Transactions

AMERICAN
FOUNDRYMEN'S ASSOCIATION

Contents

TRANSACTIONS

AMERICAN FOUNDRYMEN'S ASSOCIATION
INCORPORATED

VOL. XLVII	MARCH, 1940	No. 3

A.F.A. Organization and Personnel — 1939-40

Officers and Staff

*President, H. S. Washburn, Plainville Casting Co., Plainville, Conn.

*Vice President, L. N. Shannon, Stockham Pipe Fittings Co., Birmingham, Ala.

*Executive Vice President, C. E. Hoyt.[1]

Secretary, R. E. Kennedy.[1]

Treasurer, E. O. Jones.[1]

Technical Secretary, N. F. Hindle.[1]

Manager of Exhibits, C. E. Hoyt.[1]

Director of Safety and Hygiene Section, E. O. Jones.[1]

Assistant Secretary-Treasurer, J. Reininga.[1]

Board of Directors

Terms Expire 1940

*D. P. Forbes, Gunite Foundries Corp., Rockford, Ill.

H. B. Hanley, American Laundry Machinery Co., Rochester, N. Y.

C. J. P. Hoehn, Enterprise Foundry Co., San Francisco, Calif.

*Thomas Kaveny, Herman Pneumatic Machine Co., Pittsburgh, Pa.

James L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio.

Terms Expire 1941

*H. Bornstein, Deere & Co., Moline, Ill.

W. H. Doerfner, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

H. S. Hersey, The C. O. Bartlett & Snow Co., Cleveland, Ohio.

G. A. Seyler, The Lunkenheimer Co., Cincinnati, Ohio.

*A. Walcher, American Steel Foundries, Chicago, Ill.

Terms Expire 1942

W. B. Coleman, W. B. Coleman Co., Philadelphia, Pa.

C. R. Culling, Carondelet Foundry Co., St. Louis, Mo.

Otto A. Pfaff, American Foundry Equipment Co., Mishawaka, Ind.

Marshall Post, Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.

Fred J. Walls, International Nickel Co., Detroit, Mich.

* Member Executive Committee.
1 Association Office, 222 West Adams St., Chicago, Ill.

Production of Uniform Dense Structures in High Test and Alloy Iron Castings

Effects of Temperature of Sand Adjacent to Gates and Risers

By M. A. Scott[1], Chicago, Ill.

Abstract

To overcome problems in producing uniform, dense structure castings of high test and alloyed iron, experimental work was conducted by pouring castings through risers as gates. It was found that this method of gating and risering was very successful. The investigation carried on, as discussed in this paper, was developed from a desire to determine why shrinkage holes in some cases appeared at the gates and in the adjoining metal. From the experiments, it was observed that the temperature of the sand surrounding the gates and risers greatly influenced shrinkage. With this in mind, a gating and risering practice was developed which took into consideration the effect of hot sand. The practice has been used successfully on such castings as bushings, die wheels, rolls, etc.

1.   In the operation of a gray iron jobbing foundry engaged in the manufacture of high test and alloy iron castings, the first requisite is the production of a uniform dense structure entirely free from shrinks and porosity. Messrs. Brisbois and Cartwright have adopted successfully a method of pouring directly into the casting through the feeder head or riser, which they find applicable to a large proportion of their work, as shown in their paper[2] before the 1938 convention of the American Foundrymen's Association.

Development of Theory of Sand Heat Effect

2.   We endeavored to achieve similar results by increasing

---

the risers in both size and number until a point was reached where
the melting and cleaning costs became prohibitive. In many cases,
this method tended to increase rather than eliminate the defect.
Through close study of both failures and successes, we came to
the conclusion that the temperature of the sand, surrounding the
neck or junction between the riser and the casting, had as much,
if not more, bearing on the successful feeding of the casting, than
the temperature of the iron itself.

3.   The application of this theory commenced about the mid-
dle of 1937 when an order was received for 28 gear blanks, each
weighing 30 lb. As these were very similar in size and shape to
some with which we had formerly experienced considerable shrink-
age trouble, it was decided to try gating through the riser. This
proving successful, a mold was stripped some 45 min. after pour-
ing to determine the cause, if possible. It was found that, with the
exception of a red segment extending from the riser to the bore
(marked in white chalk, *A* of Fig. 1), the casting was black.

4.   It did not appear logical to us, if we considered the high
thermal conductivity of cast iron, that this segment should retain
this considerably higher temperature solely because it was the last
iron to enter and presumably the hottest iron in the mold. It was
quite apparent that the variation in temperatures observed in the
casting could not be accounted for by loss of temperature during
the time of pouring. It occurred to us that the flow of iron to fill
the raised hub, heated abnormally the sand above the segment, and
that in cooling, owing to the low thermal conductivity of sand, a
considerable portion of this heat was distributed through the cast-
ing rather than directly through the cope.

5.   The success of the old foundry practice of gating in the
thin sections was then explained, not by being due to the last or
hottest iron in these thin sections, but to the effect of the heavy
flow of iron heating the sand surrounding these sections and the
heat of the sand, thereby retarding their rate of cooling.

6.   Fig. 1 (B) shows a casting in the production of which a
large percentage of defectives had been encountered, after machin-
ing, due to shrinkage adjacent to the larger core. By blocking off
the two ingates to the casting and running one gate into the riser,
this defect was corrected. Fig. 1 (C) shows a pressure casting of

varying sections in which leakers were entirely eliminated by similar gating.

Further Confirmation of Hot Sand Effect Theory

7.   This hot sand theory was further borne out by the casting shown in Fig. 2. Wondering why an unsolicited order for 50 of these castings with a specified alloy analysis was received, the first one produced was broken and a shrink found in the center of the spoke "*S*." This pattern was received mounted on a board in such a manner that it was natural for the molder to gate it as in Fig. 2
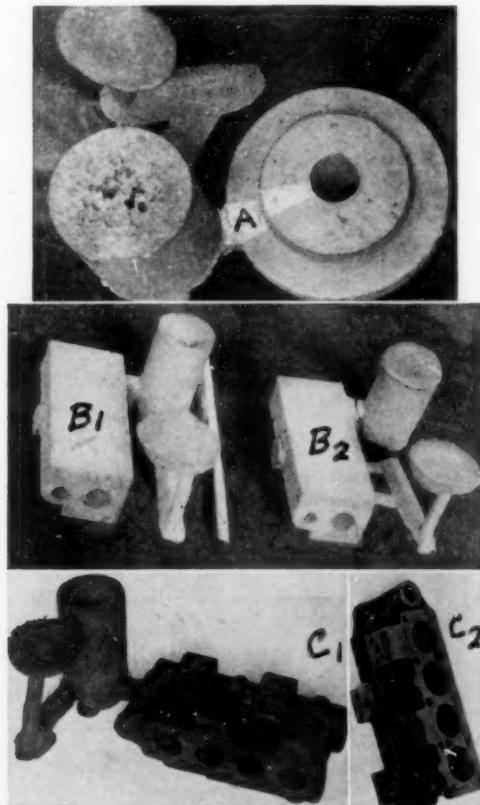
FIG. 1—(A) Casting Section Which Solidifies Last. (B1) New and (B2) Old Methods of Gating. (C) Gating Casting with Various Sections.
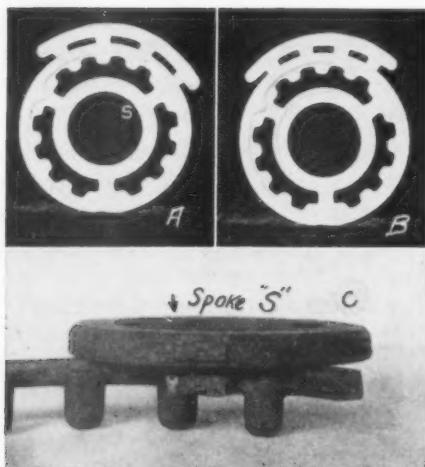
FIG. 2—(A) INCORRECT GATING OF GEAR BLANKS. (B) CORRECT GATING OF GEAR BLANKS.
(C) SHRINK CAVITY IN SPOKE.

(A), to ensure the filling of the inner ring as quickly as possible.
With this gating, some 80 per cent of the inner ring was filled
through the spoke "S." With the surrounding sand becoming
abnormally heated, the freezing of the spoke was delayed until the
remainder of the casting had solidified. This defect was remedied
by gating as in Fig. 2 (B), which permitted the inner ring to be
filled more equally through all three spokes. Having had repeat
orders with no returned defectives, we still wonder if alloys were
specified to correct this weakness, which possibly had developed in
the castings from other sources.

EXPERIMENTAL OBSERVATIONS

8. Wishing to demonstrate to our apprentice class liquid
shrinkage and the necessity for feeding, two castings (A) and (B)
of Fig. 3 were poured from a 6x6x10-in. block pattern, using two
1/4x1 1/2-in. gates at the top of the casting and eliminating any riser.
Casting (A) was cast from a 72 per cent steel mix, which, with
1.20 per cent silicon, 0.90 per cent manganese and 3.10 per cent
total carbon, is reputed to have a liquid shrinkage of 4.0 per cent
of its volume. Casting (B) was poured from a gray iron mix with
2.20 per cent silicon, 0.60 per cent manganese and 3.40 per cent
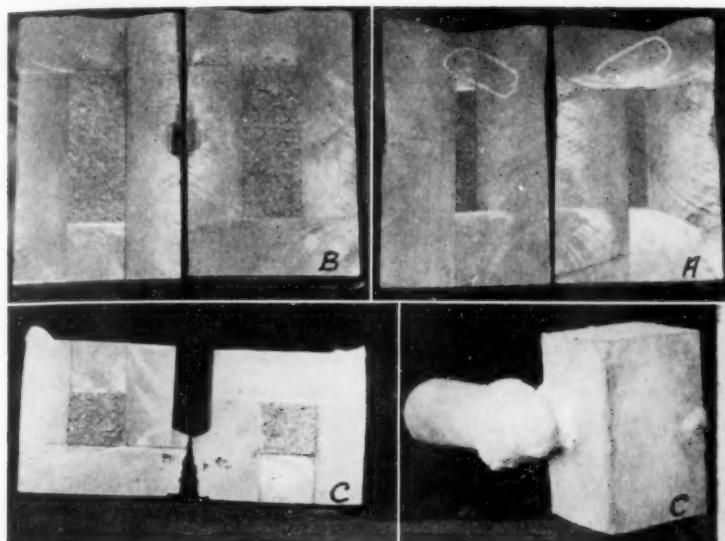
FIG. 3—(A) External Shrinkage. (B) Internal Shrinkage. (C) Shrinkage Voids from Center to Neck of Casting.

total carbon with a reputed "less than one per cent" liquid shrinkage. A third casting (C) was procured from a gray iron foundry which used a bottom gate with a side riser.

9. After cutting and breaking these castings, an examination showed that the liquid shrinkage in (A) resulted chiefly in external shrink, due to the strength of this material, while in (B), with the sides remaining straight, the shrinkage was entirely internal. In (C), the gray iron foundry casting, shrinkage voids extended from the center of the casting through the neck of the riser.

10. Two more castings, shown in Fig. 4, were made from the same pattern in the 72 per cent steel high test iron mix. Of these (A) was poured through the riser with a ¾-in. diameter vertical gate, while (B) utilized two, ¼x1½-in. gates into the casting with a top riser. After considerable discussion, as to the relative solidity of each, the castings were cut and broken in half. In both castings, the last poured or hottest iron was in the riser. As was to be expected, the core in (A) became heated to such an extent that both the casting and the riser must be considered as one unit in cooling.

11. It was now believed that with proper utilization of the

heat absorbing and low thermal conductivity properties of the sand to help, rather than hinder gating and risering problems, a considerable saving could be effected in both cleaning and melting costs.

EXPERIMENTAL PROCEDURE

12.   It was decided, if possible, to further substantiate our reasoning by procuring times and temperatures of both sand and casting during cooling.

13.   With this end in view, seven castings were poured on
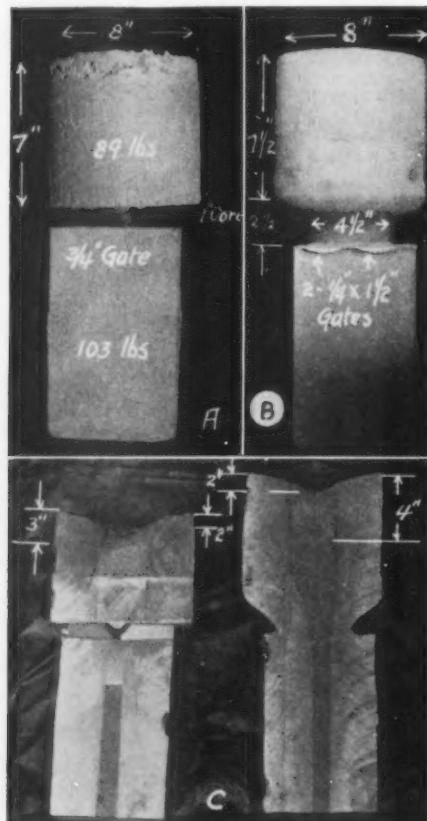
FIG. 4—(A) CASTING POURED THROUGH RISER WITH ¾-IN. VERTICAL GATE. (B) SAME CASTING POURED THROUGH RISER USING TWO HORIZONTAL GATES. (C) INTERNAL SECTIONS OF CASTINGS (A) AND (B).
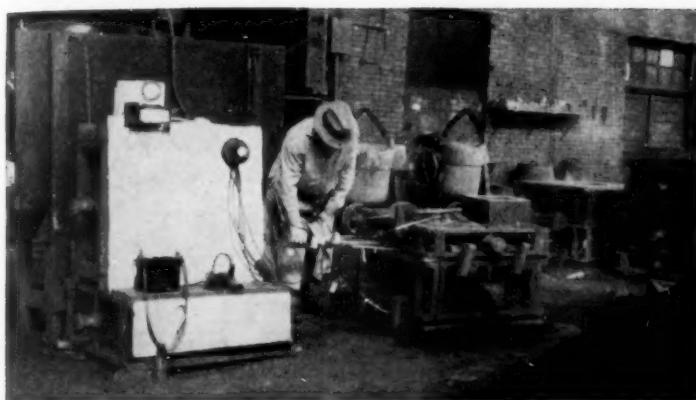
Fig. 5—Arrangement of Thermocouples, Mold, Recording Instruments and Clock
for Conducting Tests.

different days from a 72 per cent steel high test iron mix, utilizing
the following pattern equipment.

Casting   —6 x 6 x 10-in.
Neck   —2-in. square—1⅜-in. long.
Ball   —6-in. diameter—4½-in. deep.
Down Sprue—1¼-in. diameter with gate cut into ball.

14.   Thermocouples were set in both the sand and the casting,
at points selected by measurement, as shown in Fig. 5. These ther-
mocouples were connected through a switch to a calibrated record-
ing pyrometer. A laboratory "second recording" clock was started
at the commencement of pouring. Times and temperatures were
taken continuously for a period of 25 to 30 min., then periodically
every 30 min. It was found that when switching from one point to
another, where great variations of temperature were involved, it
required from 15 to 20 sec. for the needle to become sufficiently
quiet to procure a reading.

15.   Time-temperature charts made from the data thus ob-
tained (three of which are shown as Figs. 6, 7 and 8) not only
check foundry experience, but in our opinion, fully bear out the
possibilities of deliberately heating the sand to create a "hot spot,"
and thereby permit efficient feeding with smaller necks and risers.

Explanation of Data

16.   An examination of these charts discloses that the temper-
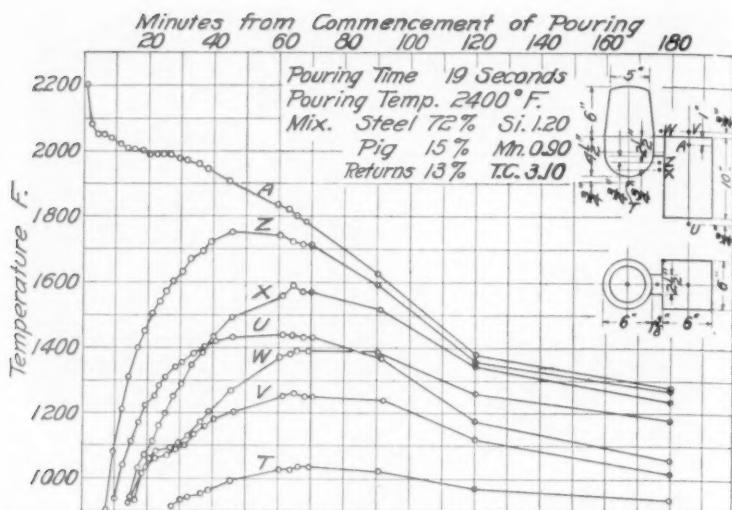
FIG. 6—TIME-TEMPERATURE CHART SHOWING RESULTS, USING POURING TIME OF 19 SEC., AND A POURING TEMPERATURE OF 2400°F. THE CURVES ARE TEMPERATURE READINGS TAKEN AT POINT INDICATED BY SKETCH AT RIGHT.
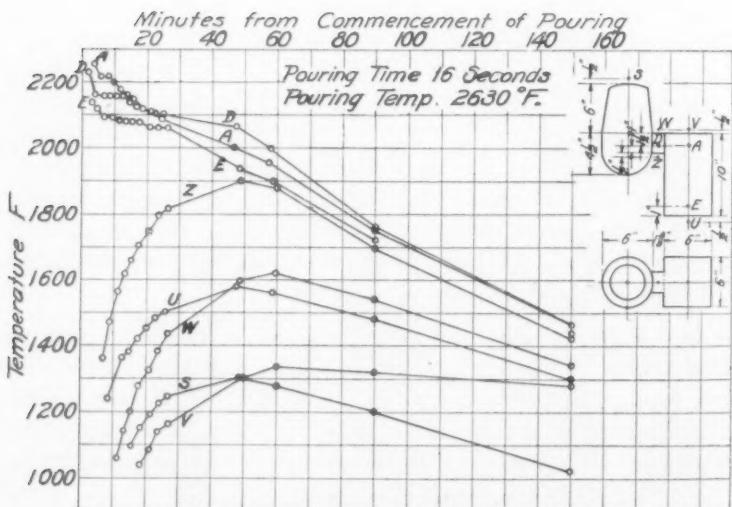
FIG. 7—TIME-TEMPERATURE CHART SHOWING RESULTS, USING POURING TIME OF 16 SEC., AND A POURING TEMPERATURE OF 2630°F. THE CURVES ARE TEMPERATURE READINGS TAKEN AT POINT INDICATED BY SKETCH AT RIGHT.
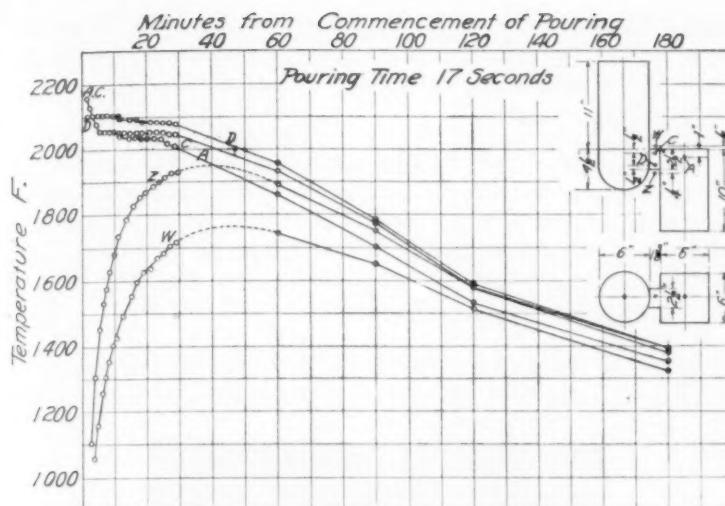
Fig. 8—Time-Temperature Chart Showing Results, Using Pouring Time of 17 sec.
The Curves Are Temperature Readings Taken at Points Indicated by Sketch at Right.

ature of the sand below the neck increases as the neck is approached and at ¼-in. from the neck ("Z" of Fig. 8), in 40 min., the sand and the casting at (A) have equal temperatures. Approaching still closer, the temperature of the sand will, it is believed, be almost equal to the freezing range of the casting.

17. The ball was extended below the neck to trap this heat and ensure it being dispelled through the iron. It logically follows that the lower the head of iron flowing over the neck, the more heat is absorbed by the sand below.

18. The sand in the drag at "U" is hotter than either in the cope at "V" or above the blind riser at "S." The point "W" is, of course, influenced by its proximity to the riser.

19. The channel at the point "D" (Figs. 7 and 8), through which feeding is accomplished, appears, through the help of hot sand below the neck, to lose temperature considerably slower than at either "C" or "A," until after the solidification range has been passed.

20. The extent to which this "hot sand" theory may be applied is shown in Fig. 9A, where all four castings, each weighing 320 lb., were equally sound. The soundness of those with the small

shrink bob is attributed to the small ingate to the ball. This necessitated very slow pouring, which permitted more heat to be absorbed by the sand below the neck as well as a considerable degree of progressive solidification.

21.   Fig. 9B shows two and three solid bushings up to 10-in. in diameter poured from a single riser. The bushings are cast to the lengths ordered and the expense of cutting off additional stock is eliminated. The risers, 5 and 6-in. in diameter, set on 5-in. balls can, it is believed, be considerably reduced in size, the limit of which has not yet been determined.

22.   Fig. 9C shows a 920 lb. die for drawing stainless steel, requiring a hardness of 235 to 250 Brinell, and a 50,000 to 55,000
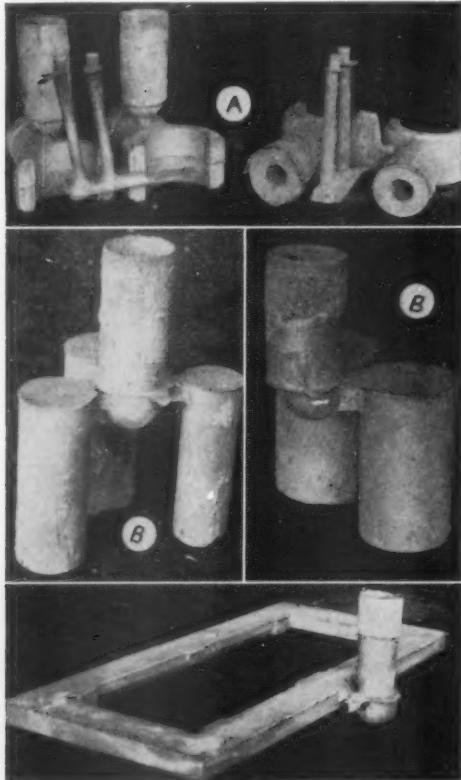
FIG. 9—OLD METHOD (LEFT) WITH LARGE RISERS COMPARED WITH NEW METHOD (RIGHT) USING SMALL SHRINK BOB. BOTH METHODS USE TWO DOWN SPRUES. THE CASTINGS ON THE RIGHT SHOW SHRINK BOB BEHIND DOWN SPRUES.

lb. per sq. in. tensile strength. This die 3 x 6 ft. outside dimension
with a 3 x 6 in. section, was gated through a 6-in. ball and a 2-in.
neck.

23.   Fig. 10A shows two dies, 117 and 209 lb., 13 x 38 in. out-
side dimensions with metal sections of 3 x 4 in. and 3 x 2 in., gated
and fed through a single riser.

24.   Fig. 10B shows four alloy rolls requiring 330 to 350
Brinell, poured through a single riser, thus permitting a reduction
of 40 per cent in molten metal requirements.

25.   Fig. 10C shows an 840 lb. gray iron flywheel, and Fig. 10D
an 860 lb. hydraulic cylinder having 50,000 lb. sq. in. tensile
strength and with a 3-in. wall. Both of these were gated success-
fully through a 6-in. riser and a 2-in. neck.

CONCLUSIONS

26.   Although there are many types of castings to which this
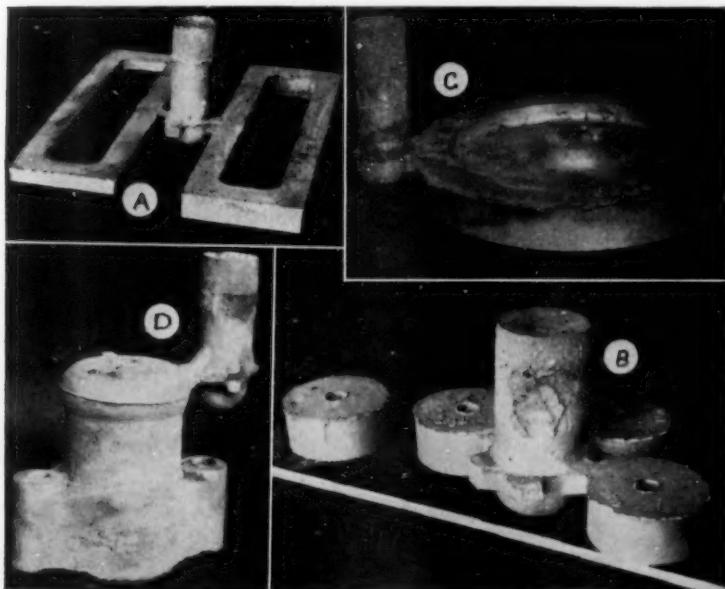
FIG. 10—(A) DIES OF 117 AND 209 LB. WEIGHT, GATED AND FED THROUGH A SINGLE
RISER. (B) FOUR ALLOY ROLLS, POURED THROUGH A SINGLE RISER, REDUCING MOLTEN METAL
REQUIREMENTS 40 PER CENT OVER OLD METHOD. (C) FLYWHEEL WEIGHING 840 LB., GATED
THROUGH A SINGLE RISER. (D) HYDRAULIC CYLINDER WEIGHING 860 LB., GATED THROUGH
A SINGLE RISER.

system is not applicable, it has been found suitable for from 80 per cent to 90 per cent of our high test and alloy jobbing castings made in dry sand, in which most of the experiments have been carried out.

27.   The gating of green sand molds is being changed gradually to this new method which so far is proving very satisfactory. However, the effect of slower pouring in green sand molds must be given more consideration than pouring in dry sand.

28.   While this system has been applied in a jobbing foundry, it is quite possible that large savings may be effected in production foundries through the assurance of sound dense castings.

29.   It is hoped, that through discussion and the experiences of other foundries, a suitable formula may be developed which will determine the minimum sizes of neck, ball and riser required to produce sound castings from any pattern. This will, of course, require a proper balance between the flow of iron required to heat the sand below the neck, the economical minimum pouring time and the degree of progressive solidification possible.

DISCUSSION

Presiding: P. T. BANCROFT, Moline, Ill.

A. K. HIGGINS[1] (*Written discussion*): We have read this paper with a great deal of interest as we read the previous paper on "Risers or Gates for Some Special Non-Ferrous and Alloyed and High Test Iron Castings" read by C. Brisbois and A. E. Cartwright at the Cleveland Convention on May 14th, 1938.

After the appearance of the paper by Messrs. Brisbois and Cartwright we tried their methods in our brass foundry with a great deal of success, although we made considerable modification in the exact method of gating the metal through the risers, from that suggested in their paper. We have since adopted these methods, with the same success in parts of our iron foundry.

For purposes of economy, both in molding time and in riser weight, we use loose runner boxes made of core sand and stop pouring when the risers still have room to take all of the metal remaining in the runner box. We use a small flow-off cut in the top of the cope, as a gauge for pouring. This method has made it possible to empty the runner boxes and reuse them for from 5 to 10 subsequent castings, the only repair necessary being another coat of blackening on the inside.

---

[1] Metallurgist, Brass Foundry, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

We found that by this method we could reduce the riser size to comparatively small dimensions. As an example, we poured experimentally a stick of aluminum bronze, 3 feet in length and 2½ inches in diameter, with no riser and with the stick set vertically and found a shrink of less than 4 inches in the top, where previous experience would lead us to expect that defects would be found through most of the length. The experiment and the result were duplicated with a manganese bronze stick casting.

As to the effects of sand heating, Mr. Scott has shown in Fig. 7 of his paper, that by his method of pouring the 6 in. x 6 in. x 10 in. block, the metal at the top of the mold, (Couple A) was about 100° F. better than that of the bottom until after the casting had frozen and feeding was no longer possible, at which time the temperature of the sand at a distance of ½ in. from the metal in the gate, showed temperatures 250° F. below the melting point of the metal, until after solidification. The same effect may be noted in Fig. 8 where the temperature spread is only about 80° F., but the distance from the metal surface is only ¼ in.

Let us try to analyze these effects. We know that the specific heat of liquid iron is about 0.15 calories per gram and its specific gravity is 7.80 while silica at the same temperature has a specific heat of about 0.30 calories per gram and a specific gravity of 2.65. We can assume that the voids in the sand will be about 20 per cent, therefore, 80 per cent solids. From these figures, it is easy to show that the effect of a maximum of ¼ in. of sand, heated to the same temperature as the metal will be the same as 0.136 in. of metal added to each side of the gate between the riser and the casting:

$$\frac{0.30 \text{x} 2.65 \text{x} 0.8 \text{x} 0.25}{0.15 \text{x} 7.8} = 0.136$$

This would make the total effective neck size 2.77 x 2.77 in. or 0.27 in. greater than the actual size. This is surely not enough in itself to feed the entire casting of 6 in. x 6 in. x 10 in. If, aside from this factor, we consider the reasons for the temperature difference between the bottom of the mold and the top, we can reach some very interesting conclusions.

The heat required to raise the temperature of the sand at any point on the wall of the gate or mold is much greater than the amount the sand is able to return to the casting before freezing is concluded. That is:

The heat required to raise the sand to its maximum temperature (that of the metal) is the average specific heat of the sand times the rise in temperature from that of the mold to that of the molten metal; (approximately 2500°) plus the heat lost by conduction while the temperature of the sand is increasing, while the heat available for keeping the metal liquid for feeding is equal only to the average specific heat of the sand times the difference between the maximum temperature of

the sand (2600°) and the freezing point of the metal, (apparently 2050° for final solidification) or 550° minus the heat lost by conduction into the mold during the time required for this temperature drop to take place.

The net result of such cooling of the metal by the sand (an even greater factor in green sand molds) is that progressive solidification of the casting from the bottom of the mold to the top is insured by the cooling of the first metal to enter the mold, with the effect of heat returned by the sand a minor one. Heating is important in that sand, previously heated (as by flowing metal) is able to absorb heat by conduction only, and in this way allows feeding through small gates. However, such drying may also be accomplished by radiation from a falling metal stream, or from the free surface of the metal in the mold.

Certain other considerations enter into this type of gating, namely the type of metal being cast. Mr. Scott's application of side gates at the top of the casting, is perhaps the best for gray iron where it is possible to break the gates from the casting. When applying top gating to bronzes and other ductile metals, we find it equally advantageous to place the riser directly on the top of the casting and to pour a stream into the riser in such a manner that it does not touch the side walls. Such placement of risers, normally makes them easier to reach with cut-off tools.

Another factor that is of greatest importance is the effect of rate of pour.

As was pointed out in the previous paper by Brisbois and Cartwright, it is theoretically possible to pour a casting with no riser if the rate of pouring is correct. Consideration shows that this "rate of pour" is a critical value and that deviation from the exact rate will result in one of two conditions. 1st—If the rate is too high, shrinkage will be found, and 2nd—If the rate is too low, the outside of the casting will show laps or cold shuts. In addition, the "rate of pour" would be constant only for long cylindrical castings. In practice, of course, such exactness is not economical and furthermore, most castings are not simple cylinders. However, if "rates of pouring" are kept as low as is practical, riser size may be diminished and soundness improved as Mr. Scott has suggested in paragraphs 17, 20 and 27.

We have used these methods on castings up to 300 lbs. in green sand, and 6,000 in dry sand on metals varying from 80-10-10 bronze to gray and white iron, with excellent results. While we may differ with Mr. Scott as to the reasons for its effectiveness, we are indebted to both Mr. Scott and to Messrs. Brisbois and Cartwright for their careful work and practical methods of presentation.

A. E. CARTWRIGHT[2] and C. C. BRISBOIS[3] (*Written Discussion*): It was with great interest that we studied the present paper concerned

    [2] [3] Metallurgist and Foundry Superintendent respectively, Robert Mitchell Co., Ltd., Montreal.

with methods for direct pouring of castings through feeding heads. The photographs and descriptions included are, without doubt, valuable practical illustrations of parallel development of methods similar to those described in our paper presented at the 1938 convention. We do fail, however, to follow the author in his reasoning regarding the significance of the effect of temperature of the sand adjacent to gates and risers. The phenomenon described in paragraph 3 of the paper seems to us to be rather unduly belabored in the matter of its explanation, and of insufficient consequence to be utilized as a theoretical basis.

Surely, any casting on being shaken sufficiently hot to visibly indicate its heat, should show redness preferentially in the location of the riser junction and the final path followed by the feeding metal; otherwise we must suppose the feeding riser wrongly placed or proportioned, and the casting imperfectly fed. This must be equally true regardless of the method of gating.

Some of the examples cited by the author in support of his "hot spot" theory are, we believe, to be more reasonably explained on the basis of progressive feeding *during pouring*. These include examples 9A, 9C, and 10A. It is inconceivable to us that the temperature of the sand at the gate could assist in making the gate-risers effective to feed the sides opposite to them in examples 9C and 10A. The freezing range of the iron used for these dies is too short to permit a degree of post-pouring feeding by the risers sufficient in itself to provide a sound casting. In these instances then, the riser (and therefore the temperature of the sand in its location) play a minor role in the result obtained. Similarly, as conceded by the author, example 9A leans largely on progressive feeding during pouring.

Coming to examples 9B and 10B, we encounter an entirely different mechanism. Here we see adequately sized and proportioned feeding heads to provide a major degree of post-pouring feeding. While the sand surface at the riser-casting junction must inevitably be very highly heated, yet we must admit that the hot fluid feeding head in close connection with the casting is the essential factor in maintaining temperature for feeding communication. Example 10C represents, in all probability, a compromise between conditions obtaining in 10A and 10B, while 10D is again a compromise, though leaning more heavily on post-pouring feeding than does 10C.

While we would naturally object to any chilling influence in the feeding path of a riser, direct-pour or otherwise, we would not like to ascribe any more virtue to the temperature of the sand surface of any part of the mold than its normally recognized insulating capacity. Where post-pouring feeding is necessary, a sufficient reservoir of fluid feeding metal is essential. If the connection between riser and casting is sufficiently short and large in area, the heat of this reservoir is the active factor in keeping the gate open; if it is not so designed the connection will freeze before it has completely functioned regardless of any temperature of the sand that has been derived from the metal in the

mold. (This excludes, of course, any source of external heating of the connection.)

We fully sympathize with the object of reducing the proportions of feeding head sizes to the practical minimum. We believe this aim to be a logical development and refinement more feasibly obtainable with direct than with indirect pouring. The possibilities for making sound, dense castings entirely without feeding heads is an intriguing study, but in practice, and especially miscellaneous jobbing practice, it is one beset with serious difficulties and uncertainties. To feed progressively and completely during pouring demands an exact calculation and balancing of pouring speed, pouring temperature, freezing range of the alloy involved, its liquid shrinkage, together with perfect control of the resistance qualities of mold and core materials. It does not seem likely that the inclusion of the "hot spot" theory into these calculations would be anything but misleading.

To attempt to control all of these variables solely by means of adjusting pouring temperature and speed is, in miscellaneous practice insufficient to produce uniform results. Fortunately there exists a means of further controlling these effects in large measure—that is by systematic use of chills and conductive mold materials, eg., silicon-carbide, graphite, metallic borings, etc.

The controlling of progressive solidification during pouring by the
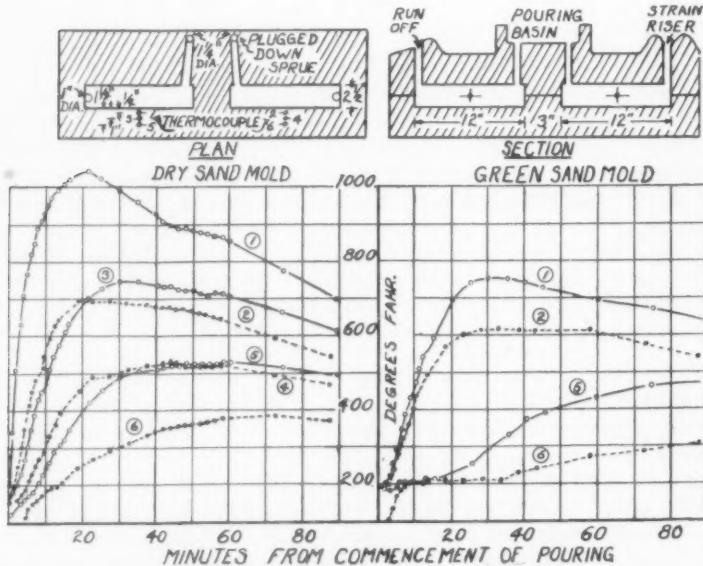
FIG. 11—CHARTS SHOWING HEATING AND COOLING OF SAND IN DRY AND GREEN SAND MOLDS. THE PLAN AND SECTION OF THE MOLDS INDICATING LOCATION OF THE THERMOCOUPLE AS SHOWN AT THE TOP OF THE FIGURE.
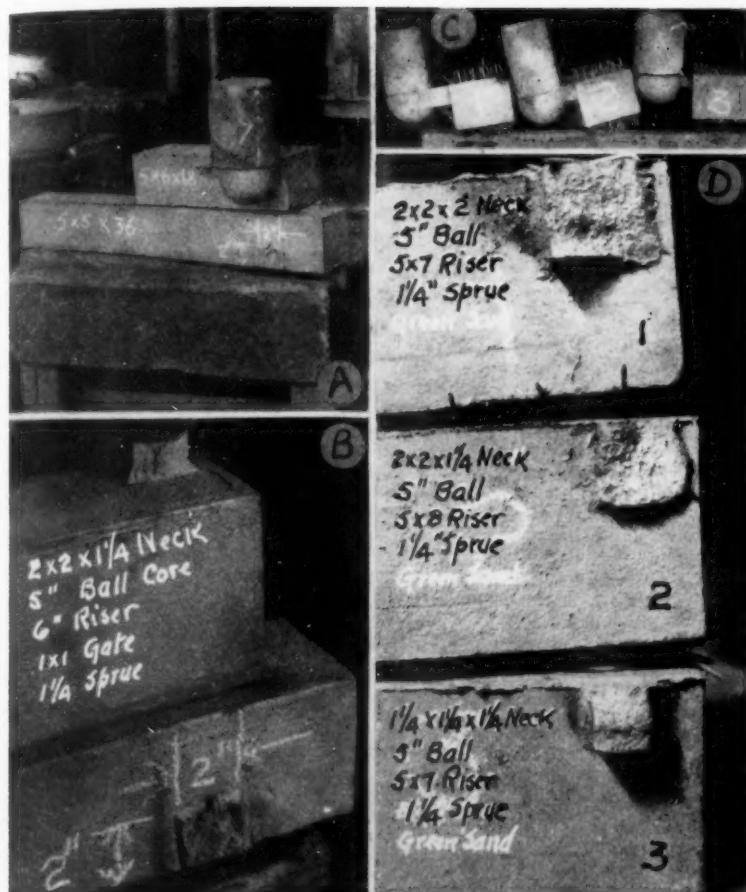
FIG. 12—(A) AND (B) TWO COMMERCIAL CASTINGS FOUND TO BE DEFECTIVE—(C) AND (D) THREE EXPERIMENTAL CASTINGS WITH VARIED SIZE NECKS AND RISERS TO DETERMINE CAUSE OF SHRINKAGE IN COMMERCIAL CASTINGS OF (A) AND (B).

aid of artificially selective cooling appears to us the logical path along which to proceed toward the reduction of the need for external feeding measures. If this is so, then any significance that could conceivably be attributed to a hot sand condition at the riser-casting connection must automatically diminish in importance along with the size of the feeding head.

M. A. SCOTT (*Written closure*): With regard to the very interesting discussion submitted by Mr. Higgins, I would like to point out that the question of heat being returned from the sand to the iron has never been raised. If the temperature curves which have been supplied are checked it will be noticed that the temperature of the sand does not

reach that of the iron till after solidification. Heat will never flow
from a colder body to a hotter one. The explanation of the hot sand
effect is that the heat loss from the metal to the hotter sand is con-
siderably less than that to the sand in other parts of the mold.

To further illustrate this point I have conducted an experiment in
which two patterns, $2\frac{1}{2}$ in. diameter, 6 in. long, were molded in the
same flask with individual down sprues and strain risers, but with a
common pouring basin. The down sprue of one casting was plugged
until a considerable amount of iron had been run through the other.
The plug being removed, both mold cavities were filled with metal of
equal temperature. Thermocouples were set on the parting line at
distances of $\frac{1}{2}$ in., 1 in. and $1\frac{1}{2}$ in. from each casting.

The time temperature charts for both dry and green sand molds
(Fig. 11) illustrate the heat absorption possibilities of sand, and when
we consider the lack of any obstruction to the thermal conductivity of
the sand the logic expressed in paragraph 17 of my paper is even
more reasonable.
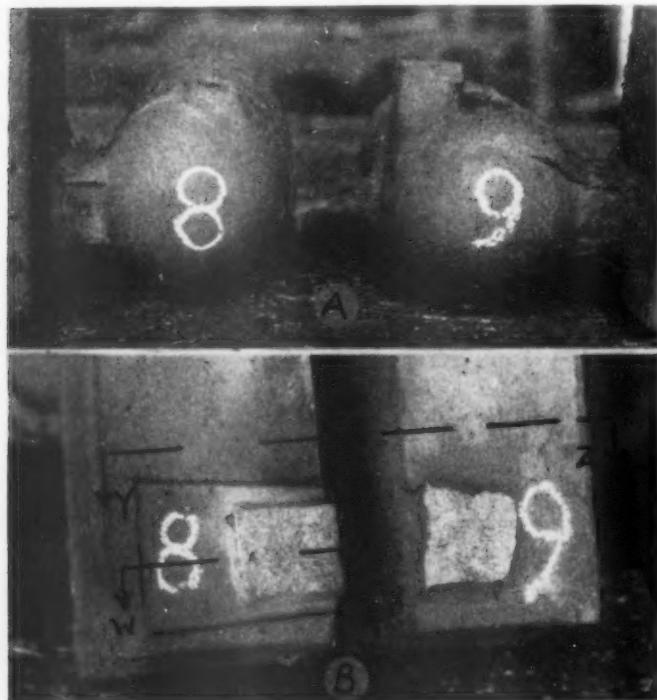
FIG. 13—TWO MORE EXPERIMENTAL CASTINGS TO DETERMINE CAUSE OF SHRINK IN
COMMERCIAL CASTINGS OF A AND B, FIG. 12. (A) VIEW OF NECKS AND BOTTOMS OF RISERS.
(B) VIEW AFTER BREAKING THROUGH THE NECKS.
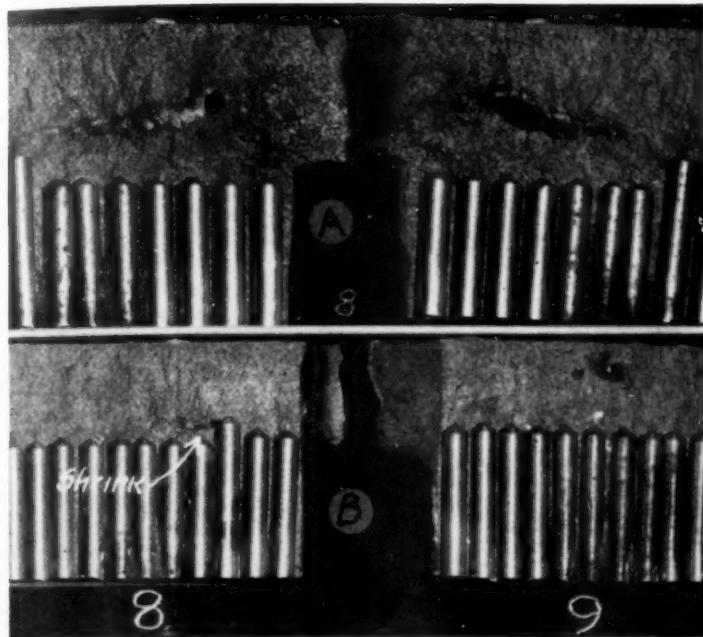
FIG. 14—(A) VIEW OF CASTING No. 8 BROKEN THROUGH SECTION W-X OF FIG. 13B.
(B) VIEW OF CASTINGS 8 AND 9 BROKEN THROUGH SECTIONS Y-Z FIG. 13B.

The discussion of Messrs. Brisbois and Cartwright is interesting and we regret we did not make our views a little more clear. All castings to a greater or less degree, are subject to progressive solidification, which if properly controlled, will remove the last point to freeze from the casting to the riser. The connecting channel between the casting and the riser must be of sufficient size to ensure its remaining liquid until the casting has completely solidified. It should also be as small as possible to permit economy in cleaning.

A recent experience demonstrated that by heating the sand below, equal efficiency may be obtained with a channel or neck approximately fifty percent the size of what we would normally have used. This experience is illustrated in Fig. 12 where the two castings (12 A) developed shrinks in the neck which extended to the center of the castings. Upon closer examination (12 B) these shrinks were located in the fillet (below the neck) in one case and actually in the sand itself in the other. In both of these a ram-up core embracing the ball and neck was employed, the rest of the mold being green sand.

Believing the size of both the ball and the riser to be ample we made three castings from the smaller pattern in green sand in which the size of the neck only was varied. These (Fig. 12 C & D) poured from the same ladle were sound in both the neck and the casting.
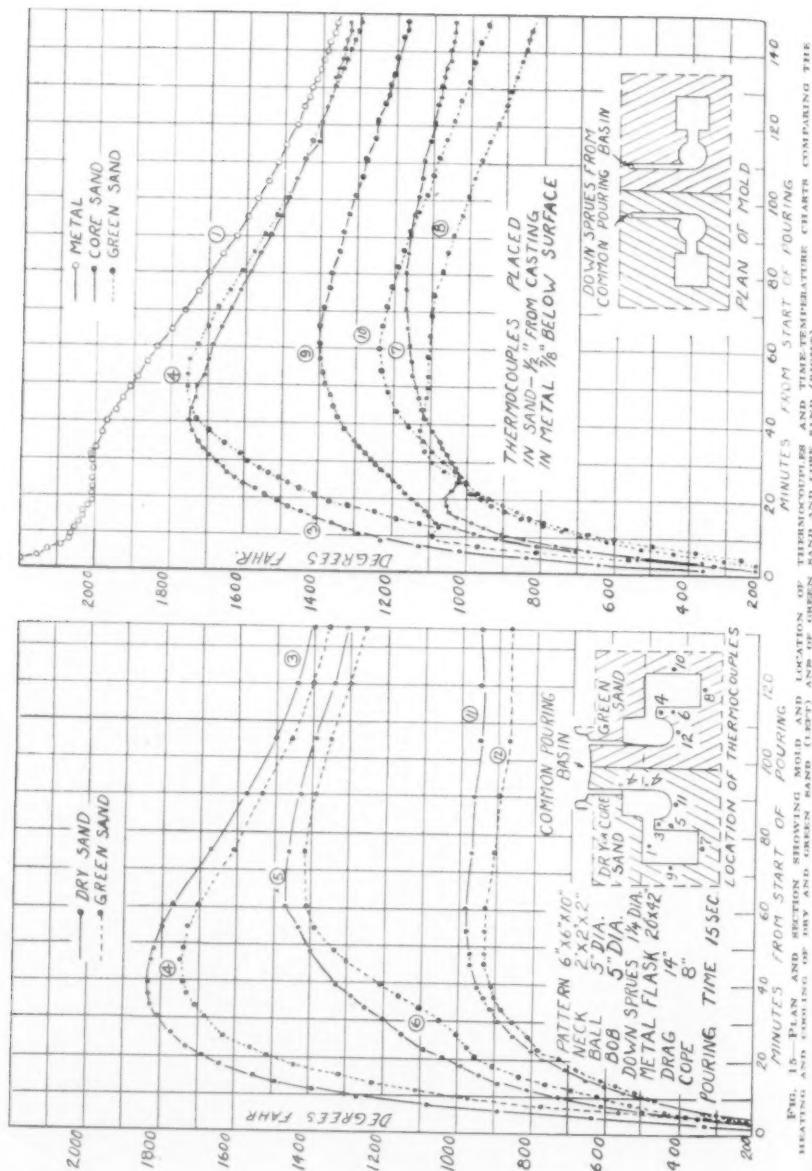
FIG. 15—PLAN AND SECTION SHOWING MOLD AND LOCATION OF THERMOCOUPLES AND TIME-TEMPERATURE CHARTS COMPARING THE HEATING AND COOLING OF DRY AND GREEN SAND (LEFT) AND OF GREEN SAND AND CORE SAND (RIGHT).

To check the effects of both the iron and the use of ram-up cores, two castings were poured from the same ladle. Number 8 (Fig. 13A) with a ram-up core developed both an external and an internal shrink (Fig. 13B) which extended from the bottom of the neck to the center of the casting (Fig. 14A and B); while number 9 in green sand, was found to be solid throughout both the neck and the casting (Fig. 13A, B, Fig. 14B). This definitely demonstrated that the shrinkage was due to the use of ram-up cores.

Thermocouples were again brought into play to determine the relative thermal conductivity of dry, green and core sands. Two molds, one of half green and half dry sand the other of half dry and half core sand were made, care being exercised in the placing of both the pattern and the thermocouples. A common pouring basin (Fig. 15) ensured the filling of both cavities of the same mold with iron of equal temperature.

From the time-temperature charts (Fig. 15) it will be seen that up to and including the solidification range, the temperature of the core sand was from 80 to 130°F. higher than that of the green sand. This "hot spot" obviously kept both the neck and the casting liquid until after the riser had solidified.

Refractories Used In the Steel Foundry

By A. V. Leun,* Bethlehem, Pa.

Introduction

1. Furnaces generally used in steel foundries may be listed as follows: (1) Furnaces for melting and refining—Open Hearth and Electric; and (2) Furnaces for annealing, strain relieving— Bung Type and Car Bottom Type.

2. In the design and construction of a furnace, the main objective is low cost per ton of product. This is directly dependent upon the life obtained from the furnace during the campaign since the preceding rebuild. To obtain the maximum life necessitates the proper choice and installation of the refractories necessary. Experience has shown that certain sections of furnaces have more severe abuse than other sections. In those locations, it is good economy to use the refractory capable of giving the furnace life, the cost of the refractory being secondary.

3. The general classification of refractory brick, produced commercially today, may be listed as silica, fireclay, high alumina— special refractory brick, sillimanite, silicon carbide, insulating refractory brick, chrome, magnesite brick. The latter two are of basic character, all of the others are of an acid nature. In those furnaces operated hot enough to produce slag, the type of slag (acid or basic) governs the choice of brick to use in contact with those slags.

Open Hearth Furnace

4. In the acid open hearth furnace, iron low in phosphorus and sulphur may be made into steel by oxidizing and slagging off the impurities. In the basic open hearth pig iron or scrap relatively high in sulphur and phosphorus is made into steel. The lining of the acid open hearth is made up of silica brick, the bottom being made up of silica brick and silica sand. This lining is gradually destroyed by ferrous and manganous oxide, and more so if there is not sufficient silicon in the original charge to make a silicate slag

in conjunction with the oxidized metals during refining. The lining of the pan or the hearth of the basic open hearth furnace i.e., those sections of the furnace enclosing the bath of the metal, is made up of magnesite or chrome brick. The bottom being burned in upon the basic brick, using a magnesite or dolomite grain, to depths varying from 8 to 16 in.

End Walls

5.   The acid open hearth furnace, as noted above, is built entirely of silica brick from the slag pockets up. The endwalls of the furnace are constructed of silica brick. The rapidity of erosion of the endwalls is dependent on the cross sectional area of the up-takes, which controls the velocity of the hot gases leaving the furnace. These hot waste gases, containing fine particles of iron, etc., when impinging on the endwalls, will cause fluxing and subsequent melting of the brick work. It has been found that velocities of waste gases below 15 ft. per sec. will result in reasonable endwall life while velocities of less than 10 ft. per sec. will often give 250 heats or better before patching is necessary. The use of reclaimed silica brick, removed from the furnace preparatory to rebuilding, in building the endwalls is economical. It is suggested that these bricks be laid in a mixture of 75 per cent ground silica brick and 25 per cent of silica cement. All joints or small cracks should be closed with this mixture. When the furnace is put into operation, the brick and cementing mixture will bond together in one piece, resulting in longer life before subsequent patching. Care should be taken to allow adequate expansion when working with silica brick to avoid pushing or bulging of the walls.

Melting Chamber

6. · The melting chamber proper is contained in the front wall, back wall, roof and hearth. The maintenance of the front and back walls often necessitates hot patching as these sections are subject to mechanical wear, slag attack and temperature. In acid furnaces, silica brick have been found to be the most advantageous brick for use in these sections from the standpoint of cost and furnace life. In basic furnaces, it is necessary to use a basic brick in those sections where slag attack is present. This includes the lower sections of the front and back wall and the hearth. In the roof and upper portions of the front and back walls, silica bricks are used. In the case of sloping back walls, good practice includes the use of basic

brick up to the skewback channels. Some furnaces have front walls
built entirely of basic brick, in some cases, steel plates being used
between the courses of brickwork. The maintaining of good front
and back walls is necessary to protect the skewback channels from
excessive heat. These channels carry the load of the roof and if
burned the roof structure will be considerably weakened, resulting
in slippage with possible failure.

Roof Construction

7. In the construction of a roof, several types are in use,
namely: ring, rib and bonded. In the ring roof, the bricks are laid
in rings from the front to the rear skewback, each ring existing
independently of the adjoining ones. In the bonded roof, each
course of brick running from the front to the rear channels over-
laps at the joints or, in other words, are bonded together. In the
rib roof, the construction is similar to the ring roof construction
except that every 4 to 8 courses a ring of longer brick is used, these
bricks extending above the contour of the roof. This type of con-
struction is claimed to give reinforcement to the roof and, in case
of failure in any section of the roof, to prevent its spread to the
entire roof.

8. The thickness of open hearth roofs, varying from 9 to
$13\frac{1}{2}$ in., depends on the capacity of the furnace and its binding.
Since these roofs are always constructed of silica brick, it is very
necessary that adequate expansion be allowed, preferably near the
ends of the furnace. It is recommended that an expansion allow-
ance of $1\frac{1}{4}$ in. for every 10 ft. of roof be allowed. In those fur-
naces, where roof wear is excessive at the rear skewback, practice
is to use a brick 3 to 4 in. longer than the main body of the roof,
these bricks extending into the furnace that distance. From 8 to 12
courses of these bricks are sufficient. This construction allows for
increased roof erosion without weakening the roof or causing it to
lose its shape.

9. In keying a roof, care must be exercised. Too tight a key
will result in pinching or spalling of the roof when coming up to
temperature. It is good practice to so key a roof that it will drop
approximately 1-in. at the center for every 6 ft. of span when re-
moving the centers. This results in small interstices between each
course of brick on the inner face of the roof. Upon heating, the

inner face, or section heating faster, will expand more rapidly resulting in these small openings closing as the roof rises. In this case, no undue strain is exerted on the brick as would normally be the case when too tight keying is practiced.

Slag Pockets

10. The slag pockets are, as their name implies, to catch as much of the slag entrained in the waste gases as possible and also to deposit the end wall wash due to erosion. It is necessary to make these pockets of sufficient size to allow for a full furnace campaign before filling up. Too small a slag pocket will result in slag running over into the checker chambers, resulting in partial blocking of the latter. Good practice calls for silica brick to be used in this section of the furnace. A volume of from 0.05 to 0.2 cu. ft. of slag is generally deposited per ton of steel per slag pocket.

Regenerators or Checkers

11. The regenerators or checkers are a very important part of the open hearth assembly both from an air preheating and draft standpoint. The primary purpose of open hearth checkers is to give as much preheat as possible to the incoming air for combustion. To obtain preheat necessitates an assembly of brick to take up heat from the hot gases leaving the furnace, subsequently giving it up to the incoming air on reversal. In determining the efficiency of a checker arrangement, two factors are of importance, namely, (1) The square feet of heating surface per cubic foot of checker volume and, (2) The horizontal flue area of the assembly. The greater the availability of heat transfer, the greater will the preheat of the air become. To make the individual horizontal flues too small will result in early blocking of the checkers during the furnace campaign with a marked drop in draft and a loss in air preheat.

12. There are a number of different checker assemblies used in practice. Space will not be taken here to go into their respective merit. However, experience has shown that generally the most economical, and yet efficient, brick assemblies are made of standard sized brick. The type of brick used in making the checker work depends on the size of the chambers and the temperatures present. It is common practice to use first quality fireclay brick, but in those chambers whose cross-sectional area is so small as to result in higher temperatures and greater dirt deposition, silica bricks often are used. Under such conditions, fireclay brick will react with the

fluxes carried over and will melt, closing up the vertical flues. Silica brick on the other hand will absorb the slag carried over and will continually decrease in thickness but will not close the flues.

13. The minimum and maximum size and heating surfaces of regenerative chambers for suitable furnace operation is an open question. However, good practice calls for a minimum of 500 sq. ft. of heating surface per ton of steel. A checker volume of not less than 150 cu. ft. per ton of steel is suggested. These figures apply to furnaces up to 40 tons capacity. For furnaces of larger rating, the volume of checker per ton of steel can be decreased markedly with satisfactory results.

ELECTRIC ARC FURNACE

14. The arc furnace consists of hearth, sidewalls, bottom and roof. This type of furnace is considerably more severe on refractory linings than is the open hearth due to its rapidity of heating and cooling and due to the bank attack and erosion, particularly around the tap hole.

15. While the difficulty in burning in the original bottom is greater than in an open hearth furnace, the maintenance of such a bottom with the aid of a suitable quick-sintering refractory material is a routine procedure. In basic furnaces, the use of any iron bonded quick-setting dolomite is economical practice.

Sidewalls

16. The sidewalls of electric arc furnaces generally are constructed of silica brick, excepting on basic furnaces in the vicinity of the tap hole where it is necessary to use a basic refractory to satisfactorily withstand the slag wash when tilting and tapping the furnace. These basic bricks are carried 5 to 7 courses above the tap hole and 2 to 3 ft. each side of it. To aid in bonding the brick, 16 gauge steel plates have been used between every other course of basic brick above the slag line. Some operators have had good results using a low iron magnesite brick in this section around the tap hole with plates being used as noted.

17. There are three hot zones on the sidewalls, due to the reflection of the arc on the walls. One of these is generally at the charging door. Due to the high temperature, the refractory life in these sections is poor. In an effort to increase the sidewall life, several methods have been used with good results. One procedure

is to use a bank of 2 to 4 water cooled pipes in the silica-brick side-wall at sections where the hop spots occur. These pipes are generally $4\frac{1}{2}$ or 9 in. from the outside shell. This allows for a rapid removal of heat away from the silica brick, keeping them cooler and resulting in a longer campaign before patching. Another method is to use the same system of cooler pipes but to use magnesite instead of silica brick. Since the conductivity of magnesite brick is higher than that of silica brick and its resistance to thermal shock greater, good results have been obtained in some furnaces from this set-up.

18. In the construction of a furnace lining, care should be taken to allow sufficient expansion radially to prevent undue strains when heating, which might result in pinching or spalling off of the inner face of the lining. Cardboard strips can be used for this purpose placing one every 4 or 5 bricks.

Roof

19. The roof of an electric furnace is generally 9 in. thick and is built of silica with silica skewback brick. These bricks, being very susceptible to thermal shock, must be heated as carefully as possible to prevent undue spalling. To increase roof life, a combination of silica and sillimanite brick has been used as follows: In assembling a new roof, sillimanite bricks are used around the electrode openings a distance of from 12 to 15 in. In addition, 4 to 6 radial spokes of sillimanite bricks are run from this center to the skewback brick. These spokes are generally 9 in. wide. Silica brick are used for the remainder of the roof between the radial spokes. If the skewback is equipped with a water-cooled pipe, it may be necessary to use sillimanite skewback brick to prevent spalling of this section. After a period of service with such a roof, it has been found that when the silica brick have been melted and spalled away to a thickness of as little as 3 in., the sillimanite brick, being more resistant to thermal shock and temperature, maintain their shape and a reasonable thickness. The roof then can be patched, replacing all of the silica brick with new ones, and put back in service. An additional roof life of 50 to 60 heats can be obtained before the silicamanite bricks wear too thin for structural strength and collapse. Since sillimanite bricks are approximately 8 times as costly as silica brick, their use necessarily must be limited to these sections where necessary. Used in the manner described, they will double the normal roof life obtained from silica brick and greatly reduce the roof cost per ton of steel produced.

LADLE REFRACTORIES

20. Ladle refractories are necessarily clay and, in the case of ladle brick, third quality clay brick are used. Experience has shown this type of brick to give the best result, due to its tendency toward swelling or over firing when under the temperature of the steel. This surface swelling will close all joints where possible slag or iron penetration might have occurred, beside presenting a tight and dense brick surface to the slag, keeping its penetration to a minimum. It is good practice to use a clay of similar refractoriness as the brick in laying the brick in the ladle. This will tend toward greater tonnage per ladle before relining is necessary.

21. Ladle brick of low refractoriness will spall and slough off excessively due to too rapid swelling. Ladle brick of high refractoriness will not present tight joints when under the temperature of the steel, and ultimately the lining will be destroyed by the necessary removal of the scull, when this scull actually has penetrated the joints between the brick.

STRESS RELIEVING OR ANNEALING FURNACES

22. Stress relieving or annealing furnaces have been built of fireclay brick with or without insulating brick[1] between the brickwork and the shell. However, today the recommended practice is to use insulating refractory brick in those sections of the furnace where abrasion is not present. Where abrasion is a factor, it is necessary to use a hard fireclay brick.

23. These furnaces may be of the bung or car-bottom types. In the car bottom furnace, either a sprung or suspended roof may be used. In those furnaces whose span does not exceed 8 to 10 ft., the use of a sprung roof is recommended. However, in those furnaces with wider spans a suspended roof should be given consideration.

24. The use of insulating refractory brick in stress relieving or annealing furnaces allows for thinner walls, faster heating, and a fuel saving generally in excess of 25 per cent. These bricks should be laid and sprayed with a suitable air-setting high temperature cement.

25. The general practice, in constructing furnaces of the above types when using fireclay brick, called for walls with a minimum thickness of 13½ in. with or without insulating brick

[1] Leun, A. V., "*Insulating Refractory Brick—Their Properties and Application,*" TRANSACTIONS AMERICAN FOUNDRYMEN'S ASSOCIATION, vol. 45, 1937, pp. 274-292.

outside of the firebrick walls. With the use of insulating refractory brick, it is possible to decrease the furnace wall thickness to as little as 9 in. Some furnaces for stress relieving have been built of insulating refractory brick using only 4½-in. walls. The brick in these walls are suspended from the shell or binding of the furnace by special hangers. The construction of furnace bottoms or tops of cars necessitates the use of fireclay brick to successfully withstand the load and abrasion of the castings charged into the furnace. It is good practice to use an insulating brick below the fireclay hearth to prevent excessive heat loss through that section.

DISCUSSION

Presiding: E. J. CARMODY, C. C. Kawin Co., Chicago.

C. E. BALES[1]: Mr. Leun mentions in his paper that standard size brick work is best for checker service. What is meant by standard size, 9 in. straights or standard size checker brick?

MR. LEUN: It happens in our steel plant we are using 9 in. x 6 in. x 2 in. checkers. When I say "standard" brick I mean brick that the brick manufacturers carry as stock and not brick made up to some fancy design of some inventor. There are a number of these specials and we pay more for them, the final cost being higher.

MR. BALES: You mean 10½ in. x 4½ in. checkers?

MR. LEUN: I am talking about brick obtainable from the manufacturer without having them made up as a special shape.

MR. BALES: I am glad to hear what Mr. Leun says about new fangled checkers and new designs because there has been a great tendency to go to those in coke ovens, and blast furnace stoves, as well as in open hearths. Some coke oven operators tell me that 9 in. x 4½ in. x 2 in. bricks are as efficient as these multi-wall checker bricks.

MR. LEUN: We use 9 in. x 6 in. x 2 in. checkers. Years ago our plant used 9 in. x 4½ x 2½ in. brick. Then they went to 3 in. brick. We feel only 2 in. of the 3 in. brick is working. So now we have gone back to the 9 in. x 6 in. x 2 in. size. We are getting more heating surface, bigger flues and faster working furnaces.

MEMBER: What materials do you use for the bottoms on acid electric furnaces?

MR. LEUN: Sharp silica sand with a little bond in it. That is all you can use on top of silica brick. I am refering to sharp silica sand, whether it is crushed rock or natural mined sand. A ganister is a sharp material.

---

[1] Ironton Firebrick Co., Ironton, O.

MEMBER: What size do you prefer to use?

MR. LEUN: That is a tough question. I can say one size, and somebody else will say "I use something else." I would say everything that will go through a 10-mesh. You want intermediate sizes below the 10-mesh, keeping out the dirt as it gives too low refractoriness. The main thing is to use a size that is going to stay where you put it without running.

MEMBER: Do you sinter your bottoms?

MR. LEUN: We try to; however, they will sinter themselves.

MEMBER: Do you sinter one layer and then put more on top or ram the complete bottom then sinter it?

MR. LEUN: Whether using sand, magnesite or dolomite, it is all right to sinter in 2 in. layers, but if you put 10 in. in and try to burn it in, you have a difficult job because you never get the temperature down to the bottom.

MEMBER: With a smaller furnace do you find you can ram a thicker bottom?

MR. LEUN: Yes, because you do not have the tendency to lift.

MEMBER: When you put in your acid bottom, do you use any binder in your sand?

MR. LEUN: If you want to use a little wood sulphate liquor, you may, because this material is a good binder in many cases. Water glass has been used with success. We use water glass for base materials, but it has a tendency to reduce the refractoriness. I think it is all right but the former binder does not in any way reduce the refractoriness.

MEMBER: What is the objection, when the whole furnace lining is out, to ramming it in with ganister? For example in small furnaces of three tons, not the large furnaces.

MR. LEUN: That is possible. We have made rammed-in linings in very small furnaces but we have never gone to the three ton furnaces with rammed-in linings. Personally, we are skeptical of their success. Others may be doing it. You always have the possibility of that rammed-in lining flaking off. You put in a brick lining, and the brick has been burned throughout by the brick manufacturer. You put in a rammed lining, and put heat on the lining then the inside face is going to behave badly for an inch or two back. This refers to any type of rammed-in lining. If you are working with acid lining, you are working with acid material. If you are working with a plastic brick mix, which some refractory manufacturers make with a mixture of fire clay and crushed brick, you have something else to work with. However, you do not dare put much plasticity in an acid lining, do you?

MEMBER: Yes. I think there are quite a number of cases around the country where it is done in the smaller furnaces.

MR. LEUN: You ram them in for 3-ton and smaller furnaces?

MEMBER: Yes.

MR. LEUN: We have rammed a 500-lb. furnace lining but no larger furnaces. Do you ram your lining in behind a form?

MEMBER: Yes, behind a nine-inch thick form. There is no water cooling in the wall. There is one course of brick in the bottom and everything else is rammed. It lasts about 150 heats on the average steel.

J. A. KAYSER[2]: The author mentioned a combination of silimanite brick and silica brick roofs for furnaces. Has he ever considered 60 per cent alumina fire brick or super-duty fire brick straight instead of mixed with silica?

MR. LEUN: I unfortunately left that point out of my paper. When the furnaces are not working 24 hr. a day we have used semi-super-duty refractory brick, in other words, Missouri brick which is practically all flint and no plastic. We have used them with good results. But when you go to 16 or 24-hr. operation, or continuous operation, we have found that type of brick is not suitable. In other words, with the continuous temperature that type of lining erodes away much faster and does not give service commensurate with what we desire from the rest of the furnace. We have tried to use high alumina brick, particularly in the side walls. These have shrinkage characteristics which we all know about and they do not quite stand the punishment that the furnace gives them.

MR. KAYSER: I want to bring out that in operation it is very often economical to use super-duty brick because they eliminate the spalling. We have in some cases used the 60 per cent alumina brick in the electrode ring and super-duty for the rest because the electrode rings get a little more punishment, and in some cases at least it is working out satisfactorily.

One other point, Mr. Leun mentioned that if in your ladle lining you used brick too highly refractory, the joints would be attacked. Wouldn't it be possible to use a refractory mortar that wouldn't be attacked?

MR. LEUN: I did not quite mean what you implied, Mr. Kayser. If we start with fire clay brick that the manufacturer advises has been burned up to 2350°F. and we put them under a temperature of 2750° or 2800°F., we will shrink the brick. When we shrink the brick, naturally the joints between the brick will open, allowing the slag

to penetrate. We need a brick which will prevent slag penetration at the joints. That is what I meant.

MR. KAYSER: I think it has been found economical anyway to use a lower grade brick and fire clay for ladles rather than to go to the expense of buying high-grade brick.

MR. LEUN: No one uses high-grade brick, even in steel ladles of 125-ton capacity. We use third quality fire clay brick. At 2150°F. the bricks start to swell. When they get up to 2350°F. the joints are tight. All third quality brick do not make good ladle brick. In other words, they may over-fire or swell too fast, and when that happens you may peel off an inch or two inches of surface. They must not over-fire too rapidly.

CHAIRMAN CARMODY: We have touched on the electric furnace and on the ladle brick, now how about the open hearth and annealing furnaces, insulating brick?

MR. LEUN: I did not discuss open hearth insulation. We are sold on 100 per cent open hearth insulation; i.e. end walls, roof and checker chambers. If it is applied properly there is no question but what insulation will work.

CHAIRMAN CARMODY: Mr. Leun, would it be possible to put your sillimanite brick in the open hearth roof, too, that is, just the framework?

MR. LEUN: Yes, it's possible. As a matter of fact, we have made arrangements to try it. As to its increasing roof life, we do not know. We have our fingers crossed. We are out for low cost of refractories. If we can add 50 or 60 heats with an expense of only $1,000 more, we are ahead of the game.

MR. KAYSER: Would you use a combination of silica brick and sillimanite brick?

MR. LEUN: In open hearth furnaces the part of the roof that goes bad is the section against the back wall. That part will wear thin and the rest may be satisfactory. If that is thin the framework fails and the roof may collapse. It is very possible that with the use of sillimanite brick in that back wall we can carry the body of the roof, that is, the middle of the roof from the front to the skew back. We have lost roofs at 190 to 200 heats where we could have saved them to 300 heats. I am talking about open hearth furnaces, which means not only steel foundry furnaces, but furnaces used in the steel plant in general.

MEMBER: How often do you have to clean your checker work?

MR. LEUN: It all depends upon the open hearth operator. It also depends upon the fuel. If the operator uses tar or pitch the checks will plug up quicker than if he uses oil or gas. It depends upon how

much fines you are carrying over. It depends also upon how you clean the hearth of the furnaces. On one of our open hearths we clean checkers every 150 heats. Another of our open hearths we get the run of the furnace without cleaning. I would say this is due purely to the type of fuel. Another thing which might have some bearing is the type of steel. If you have a steel with longer heats and higher temperatures you will have a little greater carry-over.

MEMBER: In Mr. Leun's paper he makes reference to three types of construction. Would he care to express his preference?

MR. LEUN: I will give you my opinion, but I will give you the opinions expressed by those who have advocated these assemblies. In a ring roof, you lay your brick from front to back and rear to skew back and each ring is separate. The ribbed affair is the ringed affair only every six or eight courses lengthwise of the furnace. If you are using 13½ in. roof, you use one ring of 18-in. brick. The argument used by some of its proponents is that supposing you have a section fail in the middle of the furnace, then failure will go to this one ring of 18-in. brick and stop. We used that type of construction a number of years ago. Today we are using the bonded construction 100 per cent. When patching a roof we use a ring-type construction. There it is necessary because you can patch in sections.

MEMBER: What type of refractory cement or bonding material do you prefer?

MR. LEUN: We prefer to lay silica brick dry, because there is no refractory producer in the country who makes silica cement as refractory as the brick. We know 6 per cent of alumina with 94 per cent silica gives the lowest melting point of the silica-alumina mixtures. Silica cement has around 3 or 4 per cent alumina. Why put something in along with the brick that will give a lower softening point and earlier collapse of the roof? If you get well made silica brick — and I will pay a compliment here and now to the brick manufacturers, in that they are making a brick today far superior in dimensions and size than they made a number of years ago — if you get silica brick well made and free of warpage you do not need silica cement.

MEMBER: Mr. Leun mentioned something about using a bung type roof in his pit type annealers. What type of brick is he using in those bungs?

MR. LEUN: Right now we are using clay brick. It all depends upon the temperatures you are working to. The clay brick are not entirely satisfying, but our bung type covers are failing due to abrasion and rough handling more than anything else.

MEMBER: I was thinking about annealers run at 1700°F., using insulation.

MR. LEUN: There is not a furnace built today that cannot be insulated. But the covers in our steel foundry are lifted and some are

set on edge and some laid down one on the other. Soft insulating brick would be destroyed too rapidly by this handling.

MEMBER: You say any furnace can be insulated. How about a small electric melting furnace?

MR. LEUN: You can insulate a small electric furnace.

MEMBER: What kind of refractory are you going to use on the inside?

MR. LEUN: Brick. You can insulate a furnace, can't you. Sooner or later your wall is going to wear down to a certain thickness. If you can insulate an open hearth furnace you can insulate an electric furnace. You can put insulation on any furnace. We apply it to a thickness so that when the wall gets down to a minimum thickness its mean temperature won't go above a certain temperature. Sometimes we may only put a half inch or an inch of material on. If we take an open hearth roof, that roof is originally 13½ in. thick. We might put on 6 in. of insulation. But when that roof wears back to 5, 6 or 7 in., with all that insulation on your mean temperature is too high and the roof may collapse. We use a slag wool. We make it ourselves out of blast furnace slag.

MEMBER: How do you hold that on when you tilt the furnace?

MR. LEUN: We let a brick stick up or use wrought iron nails. Understand, when you have just an inch or an inch and a quarter on there is not much strain on it. We have two 200-ton tilters. We put 3 in. of insulation on them holding it on with chicken wire. There may be cases where you may not be able to use hot insulation, such as in cases where heavy plates are on the outside. Those furnaces shells are solid and you are putting insulation between the brickwork and the shell. To repair them you must shut the furnace down.

CHAIRMAN CARMODY: How does your insulation affect your refractory life?

MR. LEUN: If you insulate a furnace and maintain the same temperature in the furnace as you had before you insulated it, the life will be the same. If you take a furnace and insulate it and don't cut the fuel back, up goes the operating temperature and you will rapidly destroy the refractories. If you maintain the same temperature as before they will last with a saving directly in fuel.

We increased our open hearth roof life by insulating them. That is contrary to the results many open hearth operators in the country have had. We have roof temperature control and other controls to aid the operators of the furnaces.

Heat and Corrosion Resistant Castings of the Chromium-Nickel-Iron Types

BY J. D. CORFIELD*, DETROIT, MICH.

Abstract

The choice of material for castings intended for use at high temperature involves consideration of two major factors, namely, resistance to chemical attack and physical strength. In oxidizing conditions a minimum of about 15 per cent of chromium plus at least 12 per cent of nickel while in a high sulphur atmosphere 24 per cent of chromium is essential.

In selecting an alloy for castings for use in a corrosive environment at normal or moderately high temperature the safest method is to expose test pieces under actual operating conditions. Where previous experience indicates the type of alloy required details of analysis should take into account the factor of "castability" and other features which render the material most adaptable to the foundry art.

INTRODUCTION

1. Chromium is impervious to progressive oxidation at normal temperature and relatively so at elevated temperatures. Likewise chromium resists the action of many other corrosive agents at normal and high temperatures. Pure metallic chromium is very difficult to produce in useable forms but even so there are many industrial applications in which pure chromium could justifiably be used at a cost of $10.00 per lb. or even more. Fortunately however chromium may, if added in sufficient amount, impart its own property of chemical inertness to other metallic elements not naturally so endowed, notably the metal iron. Thus the addition of about 12 per cent of chromium to iron results in an alloy that

* Michigan Steel Casting Company.

will not oxidize under ordinary atmospheric conditions. The addition of more chromium still further ennobles the iron, reaching the limit of its usefulness in this respect at about 35 per cent. Fig. 1. Upon this basic knowledge a distinguished family of alloys has been developed during the past 30 yr. variously called stainless, rustless, heat resisting and corrosion resisting. But regardless of what they are called, these alloys, with a few notable exceptions, are essentially alloys of iron and chromium. It is not the purpose of this paper to discuss the properties of these remarkable alloys in specific detail but rather to present a general summary which is more likely to prove of interest to the foundryman.

2.   The terms ''heat resisting'' and ''corrosion resisting'' are relative. That is, an alloy may be heat resisting or corrosion resisting only with relation to a given set of service conditions. In a sulphur bearing atmosphere at high temperature, under oxidizing conditions, the life of a comparatively high Nickel content material may be several times what it will be under reducing conditions, other factors being the same. A slight increase or decrease in temperature may produce constitutional changes in certain alloys accompanied by changes in physical properties which render the material unsafe for use above or below an optimum temperature range. Thus the suitability of an alloy for high temperature service cannot be measured in terms of temperature alone.

3.   In liquid corrosive solutions the corrosion rate depends upon a number of factors acting together or independently such as electrolytic action, oxygen content, concentration, temperature and others. And so while the alloys coming within the scope of this discussion may be grouped together under such general classifications as ''heat resisting'' and ''corrosion resisting'' they differ widely as to composition and constitution and in their chemical and physical properties.

HEAT RESISTING ALLOYS

4.   There is as yet no standardized system of classifying heat and corrosion resisting alloys according to chemical analysis. The wrought materials are generally denoted by type numbers but the numbers bear no direct relation to the chemical analysis as do the S.A.E. symbols for classifying constructional alloys. The Alloy Casting Association and the Alloy Casting Research Institute recognize three distinct types of alloys which are numbered to indicate
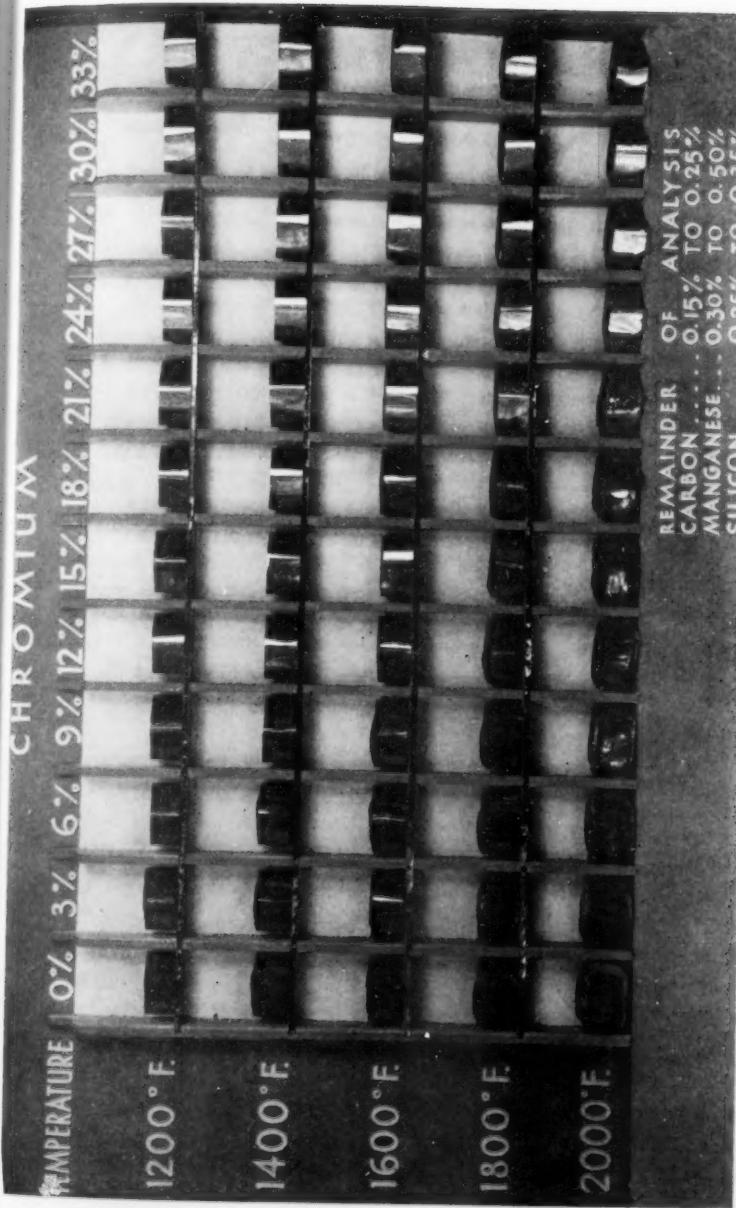
Fig. 1.—Family of Alloys Called Stainless, Rustless, Heat Resisting and Corrosion Resisting, Containing Varying Amounts of Chromium.
(*Courtesy Electro Metallurgical Co.*)

analysis ranges, each number being prefixed by the symbol NC, CN or C which designate the alloy type. For example the well known 35-15 alloy is NC-4 under the A.C.A. and A.C.R.I. system, meaning that it contains both nickel and chromium in addition to iron, but with nickel the predominating alloying addition. The No. 4 indicates the analysis range for this particular alloy which is 34—37 per cent Nickel and 14—17 per cent Chromium. In due course the tentative analysis ranges shown in Table 2 will probably be revised in conformance with the findings of the Alloy Casting Research Institute concerning the most suitable composition limits regarding manufacture and use.

Table 1

TYPICAL HEAT RESISTING ALLOYS FOR CASTINGS

Per Cent			
Chromium	Nickel	Carbon	Silicon
15	35	0.70 max.	1.60 max.
12	60	0.80 max.	1.60 max.
15	65	0.80 max.	1.60 max.
24	12	0.50 max.	1.50 max.
28	10	0.50 max.	1.50 max.
25	20	0.60 max.	1.50 max.
20	25	0.60 max.	1.50 max.
30	30	0.50 max.	1.25 max.
*28	3 max.	0.50 max.	1.25 max.
*18	3 max.	0.50 max.	1.25 max.

* These alloys are not used extensively in high temperature applications as they are subject to grain growth and embrittlement at temperatures above 1200°F.

5. In selecting an alloy for high temperature service the primary requirement is that of resistance to chemical attack which may take the form of oxidation, sulphidation, or some less easily identified reaction between the metal and the atmosphere surrounding it. In commercial heating practice the types of atmosphere most frequently encountered are those in which oxidizing or reducing conditions prevail with sulphur present in copious amount or when oxidizing or reducing conditions exist in the absence of an appreciable amount of sulphur in the products of combustion. Alloys containing a minimum of 24 per cent chromium and not more than 12 per cent nickel are generally indicated for use in a sulphur atmosphere. In a sulphur free atmosphere a higher nickel content is permissible and frequently desirable.

Table 2

ALLOY CASTING ASSOCIATION STANDARD CLASSIFICATION FOR HEAT
AND CORROSION RESISTING ALLOYS

	Per Cent	
	Nickel	Chromium
NC–1	65 to 68	15 to 19
NC–2	59 to 62	19 to 14
NC–3	37 to 40	17 to 21
NC–4	34 to 37	13 to 17
NC–5	29 to 32	8 to 12
NC–6	24 to 27	18 to 22
NC–7	17 to 20	6 to 10
C–20	3 max.	31 to 35
C–21	3 max.	26 to 30
C–22	3 max.	16 to 20
C–23	3 max.	25 to 30
C–24	3 max.	16 to 24
CN–30	10 to 13	28 to 32
CN–31	10 to 12	26 to 30
CN–32	7 to 10	26 to 30
CN–34	19 to 21	23 to 27
CN–36	10 to 13	23 to 28
CN–37	10 to 12	22 to 26
CN–38	7 to 10	17 to 23
CN–40	7 to 9	18 to 22
CN–41	10 to 12	18 to 22
CN–42	19 to 21	28 to 32
CN–43	29 to 31	28 to 32
CN–44	6 to 9	23 to 28

6. The present state of the art does not justify many definite
conclusions regarding the high temperature-sustained load strength
of the various commercial heat resisting alloys. Experience
seems to indicate that the alloys having the greatest load carrying
capacity at elevated temperatures are those which are austenitic
at normal temperature. Certain qualified opinion prefers to ex-
press the safe working stress of an alloy at high temperature as
an arbitrary function of its creep strength. Other and equally
qualified opinion holds that a more reliable method of evaluating
the high temperature load carrying capacity of an alloy is that
based upon data derived from practical service installations or
laboratory tests in which service conditions have been reproduced.
In either case the data are empirical and must admit the judgment
and experience of the designer in their application. Castings
subject to cyclic heating such as chain conveyors appear to be sub-

ject to more deformation than castings used under constant temperature and stress. On the other hand parts such as conveyor rolls can safely be used at higher than the nominal stress values considered satisfactory for stationary members. It thus becomes apparent that no single set of data can adequately represent the safe working strength of an alloy at high temperature under ALL service conditions unless the worst possible conditions are assumed which in the average case would result in an extravagant use of costly material.

7. Fortunately it has not been necessary for industry to await the accumulation of precise data concerning the properties of all combinations of chromium with nickel and iron since the empirical findings of many investigators have served to establish the use of such materials in many industrial processes of vital importance. Outstanding among these are the continuous furnaces in which many thousands of tons of finished and semi-finished products are processed daily.'

CORROSION RESISTING ALLOYS

8. Like the heat resisting alloys, the so-called corrosion resisting alloys divide themselves into three natural groups, namely those containing chromium and iron; those containing chromium-nickel and iron but with more chromium than nickel and lastly those containing also chromium-nickel and iron, but with nickel the predominating alloying element. The largest uses for plain iron-chromium alloys are in the fields of ornamentation and in the manufacture of nitric acid processing equipment. They are also

Table 3

CORROSION RESISTING ALLOYS FOR CASTINGS

Per Cent		
Chromium	Nickel	Carbon
13		0.12 max.
18		0.20 max.
28		0.30 max.
*18	8	0.07–0.20
24	12	0.15–0.25
29	9	0.20–0.30
25	20	0.15–0.25
20	25	0.15–0.25
10	20	0.20 max.

* The 18-8 alloys may also contain stabilizing additions such as molybdenum, titanium or columbium.

used to some extent to resist acid mine waters encountered in the anthracite and bituminous coal fields. By manipulating the carbon content of iron-chromium alloys containing less than 15 per cent chromium it is possible to develop a very high degree of hardness through the medium of heat treatment. It is due to this fact that we have the well known air hardening "cast to shape" die steels in widespread use at the present time.

9.   The alloys in which Nickel predominates offer very satisfactory resistance to caustic alkaline solutions, sea water, acid milk products, brine solutions and many other acid and alkali corrosive agents.

Chromium-Nickel Alloys

10.   By far the most important group of corrosion resistant alloys coming within the scope of this discussion is that one which includes the chromium-nickel series, i.e., those alloys in which the Chromium content exceeds the Nickel content in the ratio of two or more to one. These alloys offer satisfactory resistance to a large number of corrosive agents including oxidizing acids and oxidizing solutions generally. They are widely used in the oil refining industry, the sulphite pulp industry, the food handling industries, and many others. The Chromium-Nickel alloys have been studied to a greater extent than any other single group of stainless materials as a result of which a voluminous literature concerning them has grown. Practically all of this literature deals with these remarkable alloys in their wrought forms although the properties of wrought and cast chromium-nickel alloys differ to a greater extent than do those of wrought and cast carbon steel. Therefore we should consider what some of these differences are and why the analysis specifications for cast materials should not necessarily be the same as those which have been found most satisfactory for rolled products.

Carbides

11.   At the outset of this discussion it was stated that chromium, if added to iron in sufficient amount, would impart its own resistance to atmospheric and other forms of chemical corrosion. Only that part of the chromium which is in solid solution in the iron is effective in this respect. Therefore anything which would lower the concentration of the chromium-iron solid solution would have the effect of increasing the corrosion rate under a specific
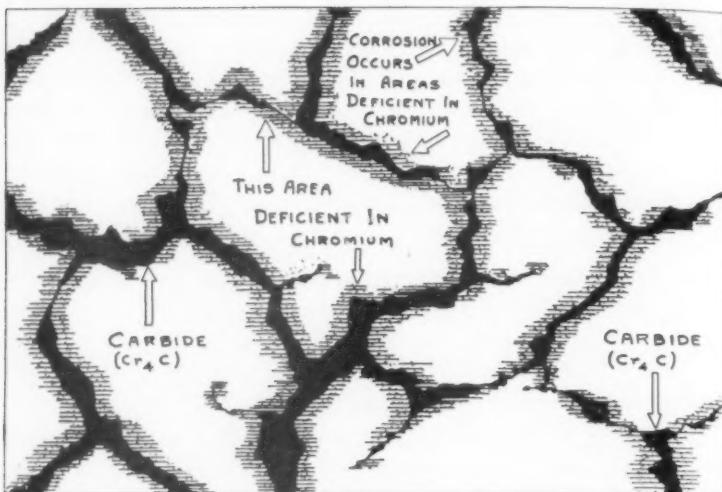
FIG. 2—MECHANISM OF INTERCRYSTALLINE CORROSION.

set of conditions. In a casting which must of necessity cool slowly in sand molds, a certain amount of carbide will form at the grain boundaries, the amount depending on the carbon content of the metal and the rate of cooling. These carbides are principally chromium carbides and the amount of chromium they contain has been taken from the solid solution and rendered useless in inhibiting corrosion. The amount of chromium thus lost may easily approximate 50 per cent of that quantitatively present in the alloy. Upon exposure to a corrosive environment corrosion will proceed along the grain boundaries as shown in Fig. 2. This type of corrosive attack is generally known as "intercrystalline" or "intergranular."

12. In many cases it is possible to avoid any trouble from precipitated carbides by heating the casting to a temperature sufficiently high to dissolve them, followed by a rapid cooling (quench) to prevent their reprecipitation during the cooling period. However it is often impractical to employ such heat treatment in the case of castings for the following reasons:

(1) The comparatively heavy wall thickness of castings generally precludes cooling at a rate fast enough to prevent reprecipitation of carbides excepting in a layer of surface material of doubtful thickness which is frequently machined away.

(2) The diversified sections of castings predisposes toward serious mechanical strains and distortion on rapid cooling.

(3) The size or shape of the casting is frequently such as to make it too cumbersome to handle with facility while at a temperature of 1900°F. or more.

Avoidance of Harmful Carbide Precipitation Effects

13. It is apparent then that to avoid the harmful effects of carbide precipitation where heat treatment is impractical, two things could be done. First, the carbon content could be kept so low that the extent of carbide precipitation would not be serious. Or, where for various reasons such as casting difficulties, this would not be feasible, the amount of Chromium could be increased so that in spite of the local loss of Chromium in the vicinity of precipitated carbides there would always be sufficient chromium left in the solution to maintain the alloy in a passive condition. In support of this view Fig. 3 shows specimens of two chromium-nickel-iron alloys which were bent approximately 120° after 72 hr. exposure in a 10 per cent boiling acid-copper-sulphate solution. Specimens 1-A and 2-A were from the same heat, of the following chemical composition: Carbon—0.06 per cent, Manganese—0.21 per cent, Silicon—1.37 per cent, Nickel—9.44 per cent, Chromium —18.06 per cent.

14. Specimens 5-A and 6-A of Fig. 4 are from another heat having the following analysis: Carbon—0.22 per cent, Manganese —0.27 per cent, Silicon—0.91 per cent, Nickel—9.20 per cent, Chromium—28.54 per cent.
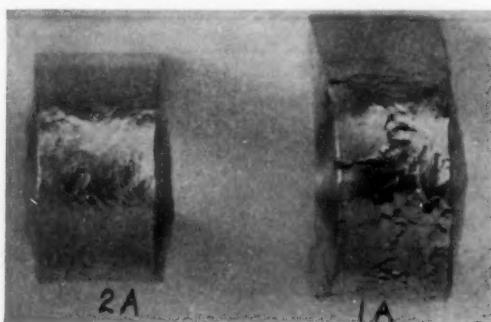
FIG. 3—SPECIMENS OF TWO CHROMIUM-NICKEL ALLOYS BENT 120° AFTER 72 HR. EXPOSURE IN 10 PER CENT BOILING ACID-COPPER-SULFATE SOLUTION. SPECIMEN 1-A WAS EXPOSED IN THE "AS CAST" CONDITION WHEREAS SPECIMEN 2-A WAS WATER QUENCHED FROM A TEMPERATURE OF 2050°F.

15. Specimens 1-A and 5-A were exposed in the "as-cast" condition whereas Specimens 2-A and 6-A were water quenched from a temperature of 2050°F. preliminary to exposure. It will be noted that specimen 1-A suffered severe intergranular attack during the test but that specimen 5-A which broke during the bending test suffered no attack whatever. In the heat treated condition neither alloy indicated visible evidence of attack.
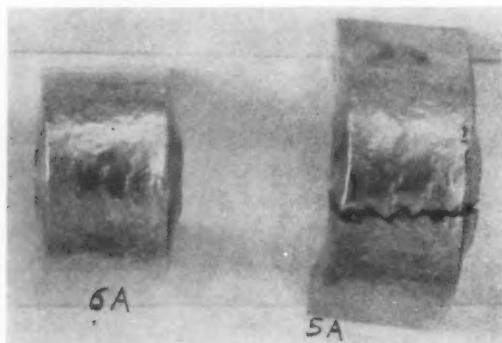
Fig. 4—Specimens of Two Chromium-Nickel Alloys Bent 120° After 72 hr. Exposure in 10 per cent Boiling Acid-Copper-Sulfate Solution. Specimen 5-A was Exposed in the "As Cast" Condition Whereas Specimen 6-A was Water Quenched From a Temperature of 2050°F.

16. It is also notable that in spite of its comparatively high carbon content (0.22 per cent) the 29-9 material was superior to the 18-8 low carbon alloy in the "as cast condition" and equal to it in the heat treated condition. In these tests the superior resistance of the 29-9 analysis to intergranular attack in the as cast condition is clearly indicated. The curves of Figs. 5 and 6 show a similar superiority with regard to its general corrosion rate in a boiling 65 per cent nitric acid solution and in these tests a third alloy was included the analysis of which was as follows: Carbon—0.10 per cent, Manganese—0.43 per cent, Silicon—1.15 per cent, Nickel—10.60 per cent, Chromium—18.15 per cent, Molybdenum—3.20 per cent. The corrosion rate is expressed in inches penetration per month in accordance with Huey's formula*. Again it will be observed that the high carbon content 29 chromium—9 nickel alloy had a lower corrosion rate than either of the 18 chromium—8 nickel alloys in the as cast condition and that it was also somewhat superior when compared with the same alloys

* Huey, W. R., "Corrosion Test for Research and Inspection of Alloys," Transaction A.S.M. Volume 18—1930.
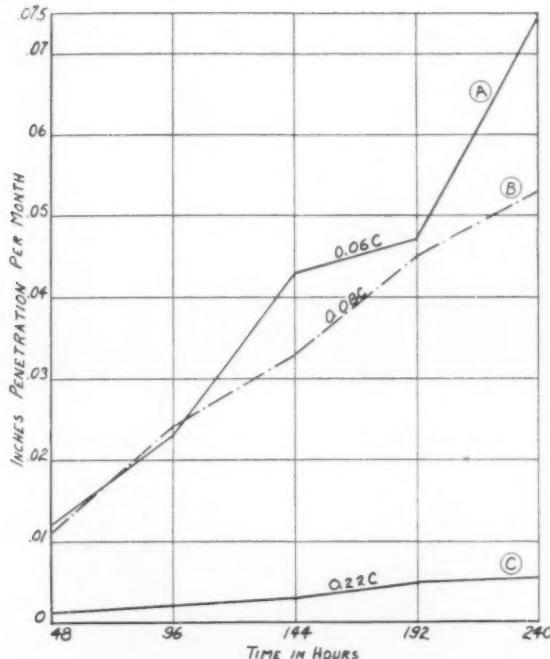
Fig. 5—Nitric Acid Corrosion Test. Alloys As Cast. Sixty-five per cent Boiling HNO₃ (A) 18 Cr. 8 Ni. (B) 18 Cr, 8 Ni, 3 Mo. (C) 29 Cr, 9 Ni.

in the heat treated condition. Incidentally it should be noted that whereas the cross-sectional area of the specimens used in the above tests were such as to insure effective heat treatment, this is not always so in the case of practical castings.

17. The above data warrant the conclusion that an alloy of approximately 29 per cent chromium—9 per cent nickel having a carbon content within the range of 0.20 to 0.30 per cent is preferable to the low carbon content of 18 chromium—8 nickel alloys for
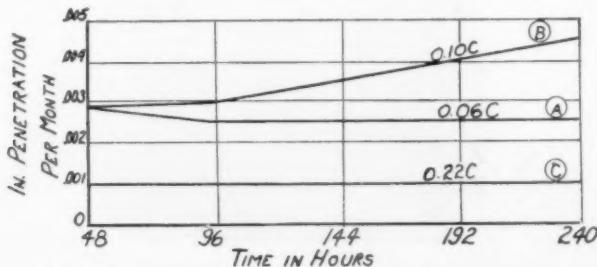
Fig. 6—Nitric Acid Corrosion Test. Alloys Quenched From High Temperature. (A) 18 Cr, 8 Ni. (B) 18 Cr, 8 Ni, 3 Mo. (C) 29 Cr, 9 Ni.
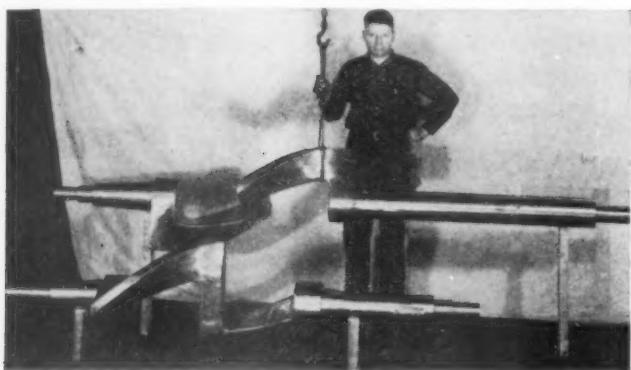
Fig. 7—Pair of Blades used in a Mixing Machine. Steel Contains 18 per cent Cr, 8 per cent Ni and 0.08 per cent C.

Fig. 8—Fractionating Tower. The Shell was Cast Centrifugally While the Trays, Bubble Caps and Fittings Were Cast in Stationary Molds. The Steel Contains 29 per cent Cr and 9 per cent Ni.

use under many service conditions and it is preferable from the foundryman's point of view since it is somewhat more fluid at normal pouring temperatures by reason of its higher permissible carbon content. This conclusion is not applicable in cases where the addition of molybdenum is indicated to achieve greater resistance to sulphate corrosion or to other corrosive agents to which molybdenum is itself particularly inert. It will be found however that an increasing number of consumers are now specifying the 29-9 alloy for casting requirements and in many cases these castings are being assembled into structures with rolled sections of 18-8 and related alloys. Producers of rolled products are limited as to the amount of chromium they can add before the problems incident to rolling become insurmountable. Consequently they place their reliance upon a low carbon content and the addition
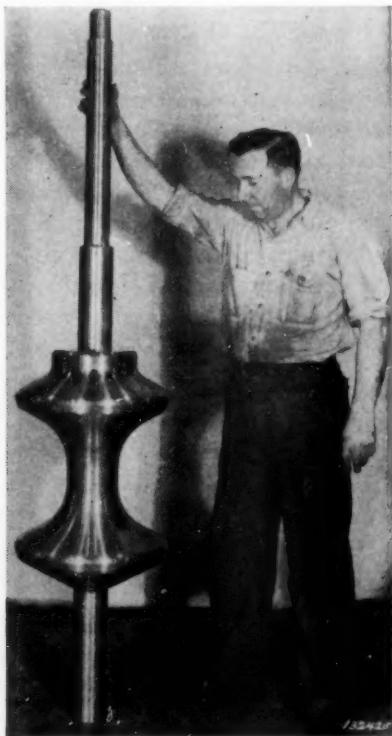
FIG. 9—STEM AND DISCS TO BE USED IN A 10 IN. VALVE. THE STEEL CONTAINS 15 PER CENT CR AND 0.20 PER CENT C WITH A BRINELL HARDNESS OF 350.

of stabilizing elements such as molybdenum, titanium and columbium to develop the necessary corrosion resisting properties. There is no reason however why the foundryman should discount his own natural advantage in this respect.

18.   The selection of materials for use under corrosive conditions like the choice of materials for use at high temperature involves the judgment and experience of producers and consumers but the accumulated knowledge based on many thousands of successful installations makes it possible to select the proper material without always resorting to the "cut and try" methods that prevailed until a few years ago.

Conclusion

19.   The choice of material for castings intended for use at high temperature involves consideration of two major factors namely, resistance to chemical attack and physical strength. Under oxidizing conditions a minimum of about 15 per cent of chromium is required plus the additions of at least 12 per cent of nickel to impart strength and toughness and also to enhance the oxidation resisting properties of the metal. In a high sulphur atmosphere a minimum of 24 per cent chromium is essential. Physical strength whether assumed as a numerical function of the "creep" strength or upon some other basis must provide against the probable contingencies of operation which determine the margin of safety required.

20.   In selecting an alloy for castings for use in a corrosive environment at normal or moderately high temperature the safest method is to expose test pieces under actual operating conditions since laboratory tests seldom anticipate the many variables which may occur under service conditions. Where previous experience indicates the type of alloy required details of analysis should take into account the factor of "castability" and other features which render the material most adaptable to the foundry art.

21.   In spite of the general lack of agreement regarding the properties of the so-called "heat and corrosion resistant" alloys these metals have been an invaluable aid to American industry in its march forward and will become ever more so in the future as we learn more about them and how best to apply them.

DISCUSSION

Presiding: J. W. BOLTON, Lunkenheimer Co., Cincinnati, Ohio.

C. T. GREENRIDGE:[1] Do you find in the 18-8 that it is preferable to run your nickel towards 9 per cent rather than 8 per cent? Do you get better results that way?

MR. CORFIELD: Yes, the higher the nickel content the lower the corrosion rate. More corrosion resistance is secured with 9 per cent nickel than with 8 per cent. One thing I would like to add. I said that we were going to try to show why the analysis specifications for cast materials should not necessarily parallel those or duplicate those which have been found most satisfactory for rolled products. I tried to prove that the 29-9 material was superior to the 18-8 low carbon alloy in the "as cast condition" and equal to it in the heat treated condition. The rolling mills are limited as to the amount of chromium they can add before the problems incident to rolling become insurmountable. Consequently they have to place their reliance upon a low carbon content. We, in the foundry, do not, and there is no reason why the foundryman should discount his own natural advantage in this respect. An alloy of approximately 29 per cent chromium—9 per cent nickel is preferable to a low carbon content 18 per cent chromium — 8 per cent nickel alloy from the foundrymen's point of view since it is somewhat more fluid at normal pouring temperatures by reason of its higher permissible carbon content.

---

[1] Battelle Memorial Institute, Columbus, Ohio.

Recommended Practice for Sand Cast Manganese Bronze

Preface

This is the third in a series of recommended practices being sponsored by the Non-Ferrous Division of the American Foundrymen's Association, the first being issued in 1934 (Transactions A.F.A., vol. 43, pp. 1-26) and the second in 1936 (Transactions A.F.A., vol. 44, pp. 33-50). Others covering the various groups of alloys listed in the Cast Metals Handbook (A.F.A. 1935), Non-Ferrous Section, will be prepared and published in the future.

Although the various practices which are treated are recommended by those considered specialists in the various fields, these practices are not intended as specifications. The alloy numbers have no particular significance other than to differentiate alloys in this particular specification. Wherever possible, those numbers are identified with existing alloy specifications.

The publishing of data relative to various alloys and treatment of such alloys by the American Foundrymen's Association, does not insure anyone using such data against liability for infringement of any patents that may now exist or are pending. It should also be understood that the publication of data concerning patented alloys or processes does not constitute a recommendation of any patent or proprietory rights that are involved.

In preparing these recommendations, the Division has attempted to collect, through reliable sources, such information as will be of practical use to foundrymen handling non-ferrous alloys.

This report is limited to sand cast manganese bronze alloys and is divided as follows:

A.   General Recommendations

1.   Molding—(a) Sand, (b) Facing, (c) Gating and Heading, (d) Cores.

2.   Melting and Pouring—(a) Types of Melting Equipment, (b) Precautions, (c) Fluxing and Deoxidizing, (d) Melting and Pouring Range.

3. Finishing

4. Heat Treatment

5. Defects, Their Cause and Prevention—(a) Melting Defects, (b) Pouring Defects, (c) Molding Sand Defects, (d) Cleaning Defects, (e) Defects Caused by Impurities in the Metal.

B. *Properties and Applications*

    1. Chemical Control Limits

    2. Typical Properties of Sand Castings

    3. Conforming Specifications

    4. Development and Field of Use.

Non-Ferrous Division Committee on Recommended Practices

T. D. STAY, *Chairman*	J. A. GANN
W. M. BALL, JR.	H. B. GARDNER
J. W. BOLTON	C. V. NASS
J. D. BURLIE	H. J. ROWE

T. C. WATTS

A. GENERAL RECOMMENDATIONS

1. *Molding*

(a) *Sand.* Considerable latitude is permitted in the grain size of the sand used for this alloy. The film of alumina carried on the surface of manganese bronze gives a fair finish even in coarse sand. A sand of about A.F.A. No. 1 or No. 2 grain size, D to F clay content; or grain fineness about 140, and clay content 5 to 20 percent, is suggested for this alloy. The alloy is quite susceptible to damage by too wet sand and a moisture content of from 5 to 6 percent is recommended.

(b) *Facing.* It is not common practice to use a facing sand for manganese bronze alloy castings, except in special cases. If the molding sand used will meet the above specifications, it will be fine enough to impart a satisfactory smoothness to the casting.

(c) *Gating and Heating.* Manganese bronze is characterized by very high shrinkage and a tendency to form dross when agitated. Castings should be designed with as uniform cross-section as possible. Where this is impracticable, generous fillets should be provided at section junctions and heads of sufficient size should be attached to the heavier sections to properly feed the shrinkage.

The drossing tendency of this alloy makes necessary special

precautions in the gating to prevent dross inclusions in the casting, generated by turbulence at the entry. Clean castings are made successfully by filling the mold by simple displacement, as in bottom pouring or any other method whereby the velocity of the stream from the gate is reduced to a minimum. Choke gates, strainer cores, and pouring basins are used successfully to prevent entry of dross from the ladle.

(d) *Cores.* The high strength of this alloy permits the use of strong cores without danger of developing excessive strains in the casting while hot. The use of silica sand with a good grade of core oil is suggested. Coating with graphite is practiced on most work to assist in removal of cores from castings. However, the finish is good on untreated cores. Due to the high shrinkage, chills are frequently imbedded in dry sand cores on work of irregular section to prevent local shrinkage. The regular practice as to venting and reenforcing applies to these alloys.

2. *Melting and Pouring*

(a) *Types of Melting Equipment.* Manganese bronze most commonly is melted for foundry use in individually fired crucible furnaces, either of the stationary or tilting types. Furnaces may be heated with gas, fuel oil, coke or electricity, although gas, fuel oil or electricity are generally used because of convenience and economy, and because their use permits close control of furnace temperature. This is true particularly when melting in electric furnaces of the induction type where zinc losses are practically negligible and almost absolute uniformity of composition may be maintained.

(b) *Precautions.* An important consideration is the temperature of melting and pouring. The metal should be poured at the lowest possible temperature at which the casting will not misrun. Due to the low boiling point of zinc, close control of the melting equipment is necessary to maintain uniformity of product. The superheat of this alloy is very low. Overheating of the metal is not necessary and should be avoided as this is accompanied by high zinc losses which change the composition of the alloy and materially alter its physical properties.

Accurate control of metal temperatures from melting furnace to pouring ladle is an essential part of foundry technique. For rapid and accurate temperature determinations a thermo-electric

pyrometer, calibrated to cover the ranges of temperatures employed, is recommended. Such an instrument may be equipped with either an open or closed end thermocouple, the latter with or without a protective tip depending on the preference of the operator. When using an unprotected tip couple, No. 8 gage asbestos or friction tape covered Chromel-Alumel wires will give satisfactory results. These couples must be used carefully, however, being agitated slightly while in the metal to prevent bridging of the wires at the surface. Because of this disadvantage, protected tip couples are finding increasing favor.

(c) *Fluxing and Deoxidizing.*   Due to the high zinc content of manganese bronze alloy, fluxes are useful as a protective covering during melting to retard the vaporization of this element. Charcoal in particular is recommended, but should be carefully dried and completely burned. While these alloys contain zinc, normally considered as a deoxidizing agent, it often is necessary to add additional deoxidizers.

(d) *Melting and Pouring Range.*   If this bronze is alloyed in the foundry, it is customary practice to produce first an intermediate or "hardening" alloy by melting the manganese, aluminum and iron with sufficient copper to obtain an alloy that will readily dissolve in copper. These hardening alloys are poured into thin ingots or slabs for remelting. In production of the final alloy, the copper is melted and sufficient of the hardening alloy is added, depending on strength requirement desired. After the hardener is completely in solution, the zinc then is introduced and the metal thoroughly stirred before casting into ingots for remelting. The ingots so cast then should be remelted for the production of sand castings.

It is also possible to obtain manganese bronze in ingot form, made to the desired composition and physical property requirements. This is perhaps the most simple method for the melting room since it is only necessary to melt such ingot, thereby eliminating irregularities in alloying practice, violent stirring prior to pouring, and double melting.

The maximum temperature in melting manganese bronze alloy should be no higher than that necessary to pour the castings satisfactorily. The superheat required for this alloy is very low; a pouring temperature within the range 1775 to 1925°F. will suffice for all work. Addition of zinc, to compensate for melting losses, is added at the end of the melting period, just prior to pouring.

3. Finishing

Gates and risers usually are removed from the castings by a band saw of suitable tooth design and operated at a speed of from 120 to 130 or more ft. per min. They also are removed by various other methods such as sprue cutters and friction wheels. Due to the fact that manganese bronze alloy does not penetrate into the molding sand, a minimum of cleaning is required. The usual methods of sand blasting, wire brushing, pickling, and water tumbling are followed.

4. Heat Treatment

Only very slight changes in physical properties are evidenced by the usual methods of heat treatment of this alloy. (Reference—British Metal Industry Handbook, no. 24, p. 237.)

5. Defects, Their Cause and Prevention

(a) Melting Defects

1. *Gas inclusions* in castings may be due to the absorption of reducing gases during melting which are released on solidification of the metal. They are revealed as bright, round holes on machining or fracturing.

Prevention—maintain as nearly as possible a neutral atmosphere in the furnace during melting and avoid overheating the metal.

2. *Oxidation* of the metal may be revealed on the surface of the casting on machining or chipping as dross inclusions and on fracturing the castings as areas of oxidized metal.

Prevention—melt under a neutral or slightly reducing atmosphere. Avoid overheating and keep the metal covered with charcoal or some other protective agent.

(b) Pouring Defects

1. *Misrun* or mold cavity incompletely filled denotes too low a pouring temperature for the design of casting and its gating methods.

Prevention—pour at higher temperature.

2. *Cold shut* or apparently cracked casting, which, on fracture, reveals an area or line along which the metal has failed to

join, can be caused by too low a pouring temperature, pouring too slowly, or a stop in the pouring.

Prevention—is indicated by the causes.

3. *Sand wash, fins, excessive burning in* and castings generally hard to clean may all be defects caused by pouring at too high a temperature.

Prevention—pour at best determined temperature.

4. *Dross* and *dirt inclusions* may be caused by careless pouring and skimming or possible lack of deoxidation.

Prevention—pour steadily, skim thoroughly, pour as close to the sprue head as possible or deoxidize.

(c) *Molding Sand Defects*

1. *Shift* caused by cope and drag flasks not matching.

Prevention—keep flasks and pins in good condition.

2. *Crush* caused by a drop of an area of the mold surface into the mold cavity on closing mold or in placing of weights on the mold.

Prevention—close molds more carefully and investigate sand conditions and condition of bottom boards and flasks.

3. *Variation in wall thickness* may be caused by shift of flasks or careless molding.

Prevention—more careful molding.

4. *Sand wash* is generally caused by soft ramming, weak or wet sand.

Prevention—ram harder, use a facing and investigate sand conditions.

5. *Sand blows* may be caused by wet sand, sand too close or improperly vented mold.

Prevention—maintain sand at proper moisture, use a more open sand or vent more freely.

6. *Core blows* generally result from damp cores or badly vented cores.

Prevention—dry cores thoroughly and vent more freely.

7. *Scabs* are caused by uneven ramming or loose sand in the mold.

Prevention—ram evenly and clean sand thoroughly.

8. *Burning into sand* is caused by soft ramming or sand too coarse and open.

Prevention—ram harder and use correct grade of sand.

9. *Shrinkage cracks or cavities* may be caused by misplacing of gates or risers may be too small.

Prevention—study nature of castings as to wall thickness and filleting and then decide the best possible manner of gating and heading.

(d) *Cleaning Defects*

All cleaning defects are caused by careless handling of the cleaning equipment, fracturing gates and risers into the casting itself or from insufficient knowledge of the size and shape of the casting.

(e) *Defects Caused by Impurities in the Metal*

Lead is the chief impurity in manganese bronze. In large castings, or in castings that are likely to be highly stressed, it is recommended that a maximum of 0.20 percent lead be permissible. There is no question but that lead has a deleterious effect on mechanical properties, shock resistance in particular. For castings unlikely to meet severe stresses, an upper limit of 0.40 percent lead is not excessive.

B.   PROPERTIES AND APPLICATIONS

1.   *Chemical Control Limits**

Table 1

MANGANESE BRONZE FOR REMELTING

A.F.A. Alloy No.		A 61	A 62†
Copper, percent............	Minimum	55.00	56.00
	Maximum...............	62.00	65.00
Zinc, percent...............	Remainder	....	....
Manganese, percent.........	Minimum	0.20	2.00
	Maximum...............	3.50	6.00
Aluminum, percent.........	Minimum	0.50	2.00
	Maximum...............	1.50	7.00
Iron, percent..............	Minimum	0.60	2.00
	Maximum...............	2.00	5.00
Tin, percent..............	Maximum...............	1.50	1.00
Lead, percent.............	Maximum...............	0.40	0.20
Nickel, percent............	Maximum...............	...	3.00

2.   *Typical Physical Properties of Sand Castings*[1]

Table 2

TYPICAL PHYSICAL PROPERTIES OF SAND CAST MANGANESE

BRONZE CASTINGS

A.F.A. Alloy No.	A 61	A 62
Ultimate Tensile Strength[2], lb. per sq. in.....	65,000 to 69,000	100,000
Yield Strength in Tension[2], lb. per sq. in.....	25,000 to 40,000	......
Elongation in 2 in.[2], percent.................	25 to 35	10
Reduction of Area[2], percent.................	20 to 30	..
Modulus of Elasticity, lb. per sq. in..........	12,200,000	..
Brinell Hardness No. (500 Kg. load, 10 mm. ball)...........................	109 to 120	..
Compression of 0.001 in.[3], lb. per sq. in.......	20,000 to 26,000	..
Compression of 0.1 in.[3], lb. per sq. in.........	85,000 to 90,000	..
Specific Gravity	8.4	..
Weight, lb. per cu. in........................	0.303	..
Patternmaker's Shrinkage, in. per ft.........	7/32	..
Izod Impact Resistance[4], ft. lb...............	20 to 40	..
Electrical Conductivity, percent annealed copper at 20°C..........................	20	..
Coefficient of Thermal Expansion per °F.....................70—200°F.	0.00001077	..
70—600°F.	0.00001210	..

---

* These specifications cover the material in the form of castings and ingot.
† Tentative Revision.
1 Mechanical properties based on specimens machined from test castings. Data shown are not to be used for specification purposes. For minimum values see conforming specifications.
2 Tensile specimens machined to provide standard ½-in. diameter by 2-in. gage section. (See Fig. 1.)
3 Compression specimens machined to 1.128-in. diameter by 1-in. high.
4 Impact specimens machined to standard Izod cantilever dimensions, 10 x 10 mm. with 45° V-notch.

3. Conforming Specifications

Table 3

SPECIFICATIONS FOR SAND CAST MANGANESE BRONZE CASTINGS

Alloy A 61—U. S. Navy Department Specification 49B3d*
Federal Specification Board Specification QQ-B-726*
Society of Automotive Engineers No. 43 Alloy
American Society for Testing Materials B7-27 (Ingot)†
American Society for Testing Materials B54-27 (Castings)†

Alloy A 62—American Society for Testing Materials B7-27 (Ingot)†
American Society for Testing Materials B54-27 (Castings)†

4. Development and Field of Use

Alloy A 61 is similar to original Parson's Manganese Bronze.
It was developed to meet the demand for a non-ferrous alloy having
great strength, toughness, and resistance to the corrosive action of
sea water.

This alloy is used for castings such as propeller hubs and blades,
valves and valve stems, engine bases and frames, pump bodies,
lever arms and other parts where strength and resistance to salt
water are required. It is also used to replace ferrous alloys where
these alloys are not suitable.
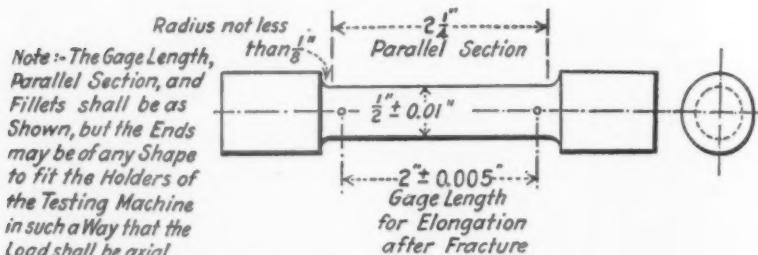
FIG. 1—DIMENSIONS OF MACHINED SPECIMENS

---

*Lead limited to maximum of 0.020 per cent.
†Tentative Revision.

The Measurement of Fluidity of Aluminum Casting Alloys

By L. W. Eastwood* and L. W. Kempf,* Cleveland, Ohio

Abstract

Since fluidity of the casting alloy melts becomes important when thin sections are poured, a fluidity test should simulate these conditions; that is, the surface area per unit of volume should be large instead of at a minimum. The results obtained from the usual fluidity test spiral having a round cross section, i.e., minimum surface per unit of volume, has been compared with those obtained from a spiral having a cross section 1¾ and ₁₆ in. thick. It has been found that the two kinds of spirals produce quite different results, those obtained with the flat spiral more nearly agreed with foundry experience. The effect of tin and silicon on the fluidity of aluminum containing 3.75 per cent magnesium and the effect of iron on the fluidity of secondary metal has been investigated by using the flat spiral test.

Introduction

1. To physicists, the term "fluidity" is the reciprocal of the viscosity, the latter term designating the internal resistance a fluid offers to internal flow. For example, tar offers a great resistance to internal flow while water or mercury at ordinary room temperature, or metals which are completely in a molten condition offer very small resistance to internal flow. The viscosity of tar is said to be high while the viscosities of the liquid metals are relatively low. To the foundryman, the term fluidity refers to the mold-filling capacity of the melt, this difference in the use of the term "fluidity" being a significant detail to recognize. In place of the term "fluidity," the foundryman frequently uses the terms "castability," "flowing power," "fluid life," "runability," or "mold-filling capacity." In this paper, the term "fluidity" will be used and, of course, will signify the mold-filling capacity of the melt, but the term "viscosity" will be used to designate the inter-

nal resistance to internal flow of the fluid. The fluidity of casting alloy melts is dependent upon two principal factors: (1) the conditions of testing, and (2) the properties of the metal.

FACTORS OF FLUIDITY

2   The conditions of testing comprise many factors, the most important of these being the form of the test piece; the rate of pouring; the degree of superheat, that is the number of degrees above the liquidus temperature; the size of the gates; the casting head; the thermal conductivity of the mold material; permeability of the molding sand and its composition; mold coatings; etc. The properties of the metal which are of greatest significance are the surface tension of the melt, the surface film on the melt, the mode of solidification and crystallization, the viscosity, the gas content, the suspended solid particles present, the thermal conductivity, and the heat capacity of the metal. It is well to bear in mind these factors which affect the fluidity of the melt, although their relative importance, with a few exceptions, will not be considered either qualitatively or quantitatively. It may be well to point out, however, that when determining the fluidity of alloy melts a standard test procedure is adopted, thereby eliminating the first set of factors which come under the heading of conditions of testing. Hence, the fluidity, as affected by the properties of the metal, can be determined though the effect of the various factors listed under this heading cannot readily be evaluated separately. The relative importance of surface tension, surface film, and viscosity will be referred to briefly below.

3.   It is well known that the viscosity of molten metals is low and does not, therefore, greatly affect the fluidity of the melt. Of course, when the liquidus temperature is reached, solid begins to form in the liquid melt and retards or completely prevents further flow of the melt in the mold cavity. Other factors the same, this occurs the most quickly in the thinnest sections. It will also be recognized that in thin sections the properties of the surface of the melt are very important because the surface area of the casting is great in comparison to its cross-sectional area. Since the melt does not wet the walls of the mold cavity, the apparent surface tension of the melt, particularly if it is enveloped in a surface film of oxide, is relatively high and constitutes a considerable hindrance to the flow of the melt into the thin sections in the mold. Molten aluminum

or aluminum alloys have relatively high surface tension as compared with a liquid such as water. Furthermore, the aluminum melt is invariably contained in an envelope of oxide, a thin skin which completely envelopes the melt either in the pot or as it flows in the mold cavity. This oxide envelope greatly increases the apparent surface tension. It is evident, then, that the foundryman becomes acutely aware of the mold-filling capacity of the casting alloys when pouring thin sections because (1) other factors the same, the fluid life of the melt is shorter in thin sections, i.e., the melt cools and solidification begins more quickly, (2) the adverse effect of surface tension and surface films is more pronounced. Bearing in mind the importance of the effect of surface tension upon the fluidity of casting alloys, the method of determining the fluidity of melts will be considered briefly.

EXPERIMENTAL TEST SPIRAL

4. The photograph, Fig. 1, shows the usual type of fluidity test casting. The mold for this casting is carefully standardized, either a vertical or a horn gate being used. The melt is poured into the mold cavity and the length of the spiral so produced is considered to be, in the usual test, a measure of the fluidity of the melt. This spiral casting has a cross-sectional diameter of $3/8$ in. and a cross-sectional area of about 0.11 sq. in. Since the cross-section is round, the ratio of the perimeter of the cross-section to the cross-sectional area is a minimum. It seems obvious that such a test casting gives the opposite of the conditions most desired because it minimizes the surface tension factor that must play a considerable role when the foundryman pours castings having thin sections. The standard test spiral was redesigned to produce a flat spiral having cross-sectional dimensions of $1 3/4$ in. wide by $1/16$ in. thick. The gate is placed in the center so that two spiral arms are formed in each casting. This spiral, shown in the photograph Fig. 2, also has a cross-sectional area of about 0.11 sq. in., but the surface area per unit of length is slightly more than three times greater than that in the usual test spiral shown in Fig. 1. When using the flat spiral shown in Fig. 2, it is necessary to take a reasonable amount of care to insure that the thickness of the spiral is the same in each mold. This can be done with very little difficulty.

5. It is generally recognized that the fluidity ratings as determined by the usual spiral test casting Fig. 1 are not consistent

with fluidity ratings based on experience in the foundry. As a consequence, the fluidity test made with this casting does not carry much significance with the practical foundryman. In order to ascertain the relative merit of the two fluidity tests, the fluidity of a number of aluminum casting alloys has been compared by using the two different spiral castings shown in Figs. 1 and 2.

Experimental Methods

6.   The spiral castings were poured in green sand, taking the necessary precautions to insure that each successive mold was
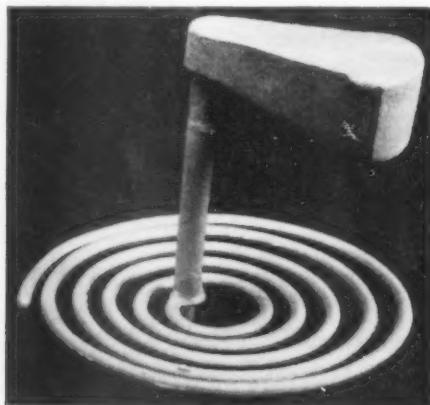
FIG. 1—ONE OF TWO SPIRAL CASTINGS USED TO DETERMINE FLUIDITY.
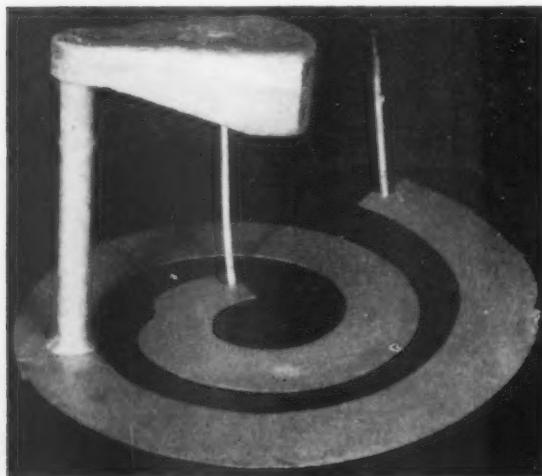
FIG. 2—FLAT SPIRAL USED IN DETERMINING FLUIDITY.

similar to the other. To eliminate the possibility of back pressure in the mold cavity, the end of each spiral is vented with a hole about 3/16 in. in diameter. Each lot of alloy investigated was melted in a plumbago crucible and brought up to the pouring temperature so that the latter was not exceeded in the furnace. The furnace is so manipulated that the temperature of the melt rises to the pouring temperature and stops without exceeding it. This procedure permits the removal of a hot crucible from the furnace since the crucible is approximately at the temperature of the metal. The metal is then quickly poured into the mold cavity, the pouring technique being standardized as much as possible. The hot crucible has the advantage that the metal is not cooled as it is poured over the lip. This is an important consideration because the mold-filling capacity of the melt, that is the fluidity, is very dependent on the pouring temperature. If variations occurred in the pouring temperature, inconsistent results would be obtained. Needless to say, though careful experimental procedure is used, some variation does occur in the results obtained with individual spirals.

7.   To insure reproducible average results, at least three melts of each lot of alloy should be investigated and two spirals poured from each melt at 1350°F. and two at 1450°F. The fluidity is measured by determining the length of the casting shown in Fig. 1 and by determining the weight and volume of the flat spiral shown in Fig. 2. The volume of the metal which will flow into the flat mold cavity is taken as a measure of the fluidity, and alloys having different densities can be compared. With this procedure, the fluidity of a given lot of alloy would be based upon the results obtained from six spiral castings for each pouring temperature.

Table 1

THE COMPOSITION OF THE ALLOYS† INVESTIGATED

Composition—Per Cent									
Alloy	Ni	Cu	Fe	Si	Mg	Mn	Zn	Ti	Total Others
3.75 Mg	....	0.10*	0.3*	0.25*	3.25-4.25	0.60*	......	......	....
3.75 Mg, 1.0 Si			Similar to 3.75 per cent Mg with 1.0 per cent Si						
4.3 Cu	....	4.00- 5.00	1.2*	1.2*	0.05*	0.30*	0.20*	......	0.2*
10 Cu	....	9.25-10.75	1.5*	......	0.15-0.35	0.30*	0.20*	......	0.3*
5 Si	....	0.40*	0.8*	4.5-6.0	0.05*	0.30*	0.20*	0.20*	0.3*
Al-Mg-Mn-Ni	1.5	......	0.4	0.4	6.00	1.00	......	......	....

*Maximum.
†The relative fluidity of the melts of these alloys is shown in Table 2.

Table 2

THE RELATIVE FLUIDITY OF SOME ALUMINUM-BASE ALLOYS AS DETERMINED BY THE ⅜ IN. DIAMETER AND 1¾ x 1/16 IN. FLUIDITY SPIRAL TESTS

	No. of Alloy Lots	Flat Spirals 1/16 x 1¾ in.			No. of[1] Tests	⅜ in. Diameter Spiral	
Alloy[2], Per Cent		No. of[1] Tests	Relative Fluidity[3] 1350°F.	1450°F.		Relative Fluidity 1350°F.	1450°F.
5 Si	2	9	100	100	5	100	100
10 Cu	3	12	87	93	4	103	103
3.75 Mg	2	8	75	75	4	77	92
3.75 Mg, 1.0 Si	3	14	78	79	10	93	99
4.3 Cu	9	34	81	86	17	87	92
6 Mg, 1 Mn, 1.5 Ni	2	7	92	83	4	103	110

[1]Total number of spirals for each pouring temperature.

[2]See Table 1 for compositions of these alloys.

[3]The volume of the metal which flows into the mold cavity of the flat 1¾ x 1/16 in. spiral, is taken as a measure of the fluidity. However, with the standard ⅜ in. diameter spiral the fluidity is determined by the length of the spiral. Since the 5 per cent silicon alloy is recognized as the most fluid alloy of this series, its fluidity is taken as 100 and the fluidities of the others are compared with it as shown.

Table 3

ORDER OF DECREASING FLUIDITY AS DETERMINED BY TWO DIFFERENT SPIRAL TESTS AT 1350°F.

1/16 x 1¾ in. Spiral		⅜ in. Diameter Spiral	
Alloy, Per Cent	Relative Fluidity	Alloy, Per Cent	Relative Fluidity
5 Si	100	10 Cu	103
6 Mg, 1 Mn, 1.5 Ni	92	6 Mg, 1 Mn, 1.5 Ni	103
10 Cu	87	5 Si	100
4.3 Cu	81	3.75 Mg, 1 Si	93
3.75 Mg, 1 Si	78	4.3 Cu	87
3.75 Mg	75	3.75 Mg	77

Table 4

ORDER OF DECREASING FLUIDITY AS DETERMINED BY TWO DIFFERENT SPIRAL TESTS AT 1450°F.

1/16 x 1¾ in. Spiral		⅜ in. Diameter Spiral	
Alloy, Per Cent	Relative Fluidity	Alloy, Per Cent	Relative Fluidity
5 Si	100	6 Mg, 1 Mn, 1.5 Ni	110
10 Cu	93	10 Cu	103
4.3 Cu	86	5 Si	100
6 Mg, 1 Mn, 1.5 Ni	83	3.75 Mg, 1 Si	99
3.75 Mg, 1 Si	79	3.75 Mg	92
3.75 Mg	75	4.3 Cu	92

Table 5

THE EFFECT OF TIN UPON THE FLUIDITY* OF THE 3.75 PER CENT MAGNESIUM ALLOY FLAT SPIRAL CASTINGS

		Pour. Temp. 1350°F.			Pour. Temp. 1450°F.		
Alloy, Per Cent	No. of lots Tested	No. of Spirals	Fluidity Vol.cc	Relative	No. of Spirals	Fluidity Vol.cc	Relative
3.75 Mg	4	8	11.55	100.0	8	22.4	100.0
3.75 Mg + 0.5 Sn	4	8	15.20	131.5	8	24.3	108.5

* Measured by the flat fluidity test spiral.

8. In the initial part of the investigation, less than six spirals were poured from each temperature as the data in Table 2 shows. This table indicates the various alloys investigated, the number of lots of each alloy tested, the number of spirals poured and the fluidity as determined by the two types of spirals. The compositions of these alloys are given in Table 1.

9. The comparison of the results obtained by the two different spiral castings shows that the rating for the various alloys differs considerably, depending upon which type of spiral casting was used. It is generally agreed that the 5 per cent silicon alloy is the most fluid of these alloys. To facilitate comparison, the fluidity of this alloy for a given pouring temperature was taken as 100. The order of decreasing fluidity as determined by the two different spiral tests at a pouring temperature of 1350°F. is shown in Table 3, while in Table 4 the order of decreasing fluidity at a pouring temperature of 1450°F. is shown.

10. The difference in results obtained by the two test castings is quite pronounced. Thus, at a pouring temperature of 1450°F., the experimental alloy containing 6 per cent magnesium, 1 per cent manganese, and 1.5 per cent nickel appears very fluid as measured by the 3/8 in. diameter spiral, i.e., 10 per cent better than the aluminum 5 per cent silicon alloy. The flat spiral, however, shows that this alloy is 17 per cent less fluid than the 5 per cent silicon alloy, and this result definitely checks foundry experience. While the various foundrymen may not and do not necessarily agree as to the relative fluidity of these alloys, at least the order of fluidity, as determined by the flat spiral, more nearly represents foundry opinion than does the result obtained with the standard spiral having a round cross section. On the basis of this result, it is concluded that the flat spiral gives a more accurate fluidity rating of the melt than the usual spiral having a round cross section. Sufficient experience with the flat spiral as a measure of fluidity has not yet been attained to properly rate its value as a foundry test. One of the principal disadvantages of any such fluidity test is the large number of molds required.

Alloy Effect on Test Spiral

11. The effect of tin upon the fluidity of the 3.75 per cent magnesium alloy has been determined by using the flat spiral, and the results are reported in Table 5. Likewise, the effect of silicon upon the fluidity of the 3.75 per cent magnesium alloy has also

Table 6

THE EFFECT OF SILICON UPON THE FLUIDITY* OF THE 3.75 PER CENT MAGNESIUM ALLOY

Alloy, Per Cent	No. of Melts Tested	No. of Spirals	Pour. Temp. 1350°F. Fluidity		No. of Spirals	Pour. Temp. 1450°F. Fluidity	
			Vol.cc	Relative		Vol.cc	Relative
3.75 Mg	3	6	11.30	100	6	22.9	100
3.75 Mg + 1.75 Si	3	6	14.95	132	6	25.5	117
3.75 Mg + 2.20 Si	3	6	16.70	148	6	27.5	126
3.75 Mg + 2.75 Si	3	6	18.15	162	6	27.8	127

* Measured by the flat fluidity test spiral.

Table 7

THE EFFECT OF IRON CONTENT UPON THE FLUIDITY** OF SECONDARY METAL*

Fe, Per Cent	No. of Spirals	Pour. Temp. 1350°F. Fluidity		No. of Spirals	Pour. Temp. 1450°F. Fluidity	
		Vol.cc	Relative		Vol.cc	Relative
0.37	6	23.2	100	6	34.8	100.0
0.80	6	22.4	97	6	33.8	97.0
1.20	6	23.6	102	6	36.1	103.7
2.00	6	26.5	114	6	37.4	107.5

*Copper 6.8 per cent, Iron 0.37 per cent, Silicon 4.08 per cent, Zinc 1.90 per cent, Manganese 0.37 per cent.
** Measured by the flat fluidity test spiral.

Table 8

THE FLUIDITY† OF VARIOUS LOTS OF AN ALUMINUM-BASE ALLOY CONTAINING 3.75 PER CENT MAGNESIUM AND 1.0 PER CENT SILICON

Lot	Pour. Temp. 1350°F. No. of Spirals	Fluidity**	Pour. Temp. 1450°F. No. of Spirals	Fluidity**	Remarks
A	4	76.2	4	80.3	Satisfactory
B*	2	79.0	2	73.8	Misrun
C	4	78.0	4	83.0	Satisfactory
B*	4	79.0	4	77.5	Check made on lot B.

*Misruns reported in the foundry when pouring green sand castings having thin sections. Lots A and C were considered satisfactory. Pouring temperature used in the foundry: 1425°F.
**The fluidity of 5 per cent silicon alloy poured under similar conditions taken as 100. See Table 2.
†The fluidity was determined by foundry experience and by the use of the flat fluidity spiral.

been determined with the flat spiral, and the results are reported in Table 6. The effect of iron upon the fluidity of a secondary metal containing approximately 7 per cent copper, 4 per cent silicon, and 2 per cent zinc, has also been investigated and the results are reported in Table 7. These data show that an increase in the iron content from 0.37 per cent to 0.80 per cent has little effect on the fluidity, probably decreasing it slightly. An increase in the iron to 1.2 and 2.0 per cent progressively increases the fluidity, the increase being quite marked at the higher iron content.

12. The differences in fluidity observed in alloys having different compositions, such as those shown by the data in Tables 2, 5, 6 and 7, are large and fairly easily measured. However, foundrymen frequently report differences in fluidity characteristics of different lots of the same alloy. Thus, it sometimes happens that a given lot of alloy will produce satisfactory castings, but when a different lot of alloy is used, misruns are encountered. Such experiences are complicated by the fact that the misruns might be caused by a number of factors other than those attributable to the metal. For example, it has become increasingly clear that differences in fluidity among different lots of the same alloy or even among different alloys of aluminum can be readily offset by relatively small differences in pouring temperature. However, there are slight differences in the fluidity of various lots of the same alloy, and the detection of such differences in fluidity is the true test of the sensitivity and value of the flat spiral as a foundry test. Table 8 shows the fluidity data on a few lots of aluminum containing 3.75 per cent magnesium and 1 per cent silicon. Observations made on the relative fluidity of the various lots of alloy as determined by foundry experience are also included in this table. It will be noted that the observations made in the foundry check the fluidity measurements obained with the flat spiral.

Summary

13. Since fluidity of the casting alloy melts becomes important when thin sections are poured, a fluidity test should simulate these conditions; that is, the surface area per unit of volume should be large instead of a minimum. The results obtained from the usual fluidity test spiral having a round cross section, i.e., minimum surface per unit of volume, has been compared with those obtained from a spiral having a cross section 1¾ in. wide and 1/16 in. thick. It has been found that the two kinds of spirals produce quite different results with aluminum alloys, those obtained with the flat spiral more nearly agreeing with foundry experience. The effect of tin and silicon on the fluidity of aluminum containing 3.75 per cent magnesium and the effect of iron on the fluidity of secondary metal has been investigated by using the flat spiral test.

DISCUSSION

Presiding: GEO. P. HALLIWELL, H. Kramer Co., Chicago, Ill.

H. B. GARDNER[1]: I believe this method of test has very interesting possibilities once you have had an opportunity to try it out. A question I have relates to Fig. 2, showing the spiral running in both directions. I wonder if the one spiral might possibly feed the other, but after one has tried the test himself, he would soon answer that question.

I like very much Mr. Kempf's method of insuring a hot pouring lip. We at the Bureau recognize that we have a cold pouring lip and to get around that, in part, at least, we always pour a full-sized ingot before we pour any spirals.

MEMBER: What type sand was used and what was its moisture content?

MR. KEMPF: The sand used was a natural bonded Ohio sand falling between A.F.A. classifications 1G and 2G. Its moisture content was about 6 to 7 per cent. The permeability was relatively low, probably around 4 to 8 per cent.

MEMBER: Are the lengths of those flat spirals easily measured? On the end, aren't they apt to be quite irregular?

MR. KEMPF: They are very difficult to measure as far as length goes, and we don't measure the length. We weigh them calculating the volume of metal and have found that this procedure works very well.

MEMBER: Mr. Kempf mentioned the importance of surface tension as a factor in fluidity tests. I wonder if he has done or has any methods of measuring surface tension and can tell us what the relationship really is?

MR. KEMPF: We have spent considerable time attempting to devise a simple and readily applicable method of determining surface tension of molten aluminum. It is not an easy job. Probably the most promising method, if there is any degree in the differences, is one which is an application of the submerged bubble method. The pressure required to form a bubble on the end of a capillary tube submerged in the liquid metal is measured from which the surface tension can be readily calculated. We have also obtained quite good indications from the old-time wire loop method, which many have used in physics laboratory courses in college. All that is necessary is a wire that is not acted upon by the metal. We can approach that very closely by putting coatings on tungsten wires that are resistant to aluminum. We have come to the conclusion that in these measurements of surface tension, we don't know exactly what we are measuring, either. We are apparently measuring the surface tension of the oxide which forms on the molten metal. It is different from measuring the surface tension of water because oxide is

---

[1]Research Associate, National Bureau of Standards, Washington, D. C.

always there. From the measurements which we have made, though, this apparent surface tension seems to vary in the same way with temperature as does the flowability or fluidity of metal as it is determined in these casting tests.

MEMBER: The thought that I had in mind was that if we could get a proper direction for some of these tests for flowability as related to surface tension, we might put a stirring rod in and measure the force of stirring the metal and the viscosity relationship would come into play. Do you think such a possibility exists?

MR. KEMPF: That would measure something different, the viscosity of the metal or the internal resistance of the metal to flow. There has been one attempt that I know of, made perhaps 15 or 20 years ago, by an Italian, to measure the viscosity of metals in some such manner, and the results which he got appeared quite reasonable. We never have had occasion to try the method ourselves.

CHAIRMAN HALLIWELL: In partial answer to Mr. Kempf's remark about suggesting to the Committee on Fluidity the changing of the nomenclature, I can say that that has already been taken up. It was discussed at the committee meeting today.

I do not quite agree with Mr. Kempf's suggestion that we raise the temperature sometimes if we want to increase our fluidity on a certain alloy. On some occasions when we have come in contact with that situation we have had a discoloration of the casting, which the customer doesn't like, especially when it is on the surface and it cannot be cleaned up. That discoloration comes when you increase the temperature and will disappear when you drop the temperature. But if you drop the temperature, you lose your fluidity.

MR. KEMPF: I agree completely with Mr. Halliwell. The difficulty with the particular job that was referred to in one of my slides, where one heat of metal gave a satisfactory casting and the next heat of metal did not, could not be cured by increasing the pouring temperature; those castings could be run if the temperature was increased as little as 25°F., but when you increased the temperature, then we ran into surface shrinkage, and the surface shrinkage was just as undesirable in this particular case as misruns.

CHAIRMAN HALLIWELL: Surface shrinkage, which some foundrymen call "chicken tracks" is very disconcerting.

MEMBER: Is there any relationship between the castability of an alloy as measured by the fluidity test and the internal heating of that metal, which would not be governed at all by the surface tension in the metal? Is there any relationship in order between the metals that show excellent properties for heating up well and the fluidity of that metal?

MR. KEMPF: I do not see any relationship whatever.

MEMBER: Is this method of green sand adaptable to permanent molds; in preheating such molds and finding out the rate of extraction of the heat from the metal as it goes into the mold?

MR. KEMPF: We gave a great deal of consideration to the question of whether or not we should make up this mold in iron, in other words, make it a permanent mold. We have not tried this specific casting in a permanent mold but we have compared sand and permanent mold castings in many other types of experimental castings. We very definitely feel that it is far more difficult to maintain conditions fixed in a permanent mold than it is in a sand mold, primarily because you have to heat the permanent mold or, if you do not, it is heated anyway, if you are going to make more than one casting. It is difficult to maintain a metal mold at a fixed temperature without a great deal of labor and a great deal of time. Also, there is the question of the surface of the iron mold. If you use a bare surface, it is not going to stay bare long; it is going to oxidize and the characteristics of your mold are going to change as the iron oxidizes. If you use a coating, there is the question of thickness of coating and the surface texture of the coating, both of which are very important in the apparent fluidity of the metal. We finally decided that the sand casting was the more adaptable as far as the control of the testing conditions was concerned.

The Flowability of Cast Steel

By E. C. KRON* AND C. H. LORIG*, COLUMBUS, OHIO

Abstract

Flowability tests, using molds of the type proposed by Ruff, were carried out in the laboratory on 14-lb. heats of steel and were later extended to include studies of the flowing qualities of large size laboratory and open hearth heats employing a special test mold. In order to apply the test in the foundry to steel in the ladle ready for casting, a mold was designed so as to discard about 100-lb. of steel before the test channels were filled. This was done to allow the nozzle or lip of the ladle and the various channels in the mold to reach steel temperatures before the test proper was made. The literature on the measurement of flowability of cast steel was reviewed. Fairly consistent results were obtained in the laboratory with a modified Ruff mold. Temperature-length of flow curves ran more or less parallel for steels containing varying amounts of carbon, silicon, manganese, and copper; and indicate that the flowing qualities of the steel were improved moderately by increased amounts of these elements. Titanium in the high manganese, high silicon, copper type of cast steel appeared to affect the flowability adversely at high steel temperatures. Laboratory tests employing the special mold in which 120-lb. heats were poured, appeared to give fairly reliable values for the flowing qualities of steel. The mold, after changing dimensions of several of the flow channels, was later employed in the foundry for measuring the flowability of 27-ton, open hearth heats at various times during the cast. Results of the experiments in the foundry showed that the method had the necessary attributes of a workable plant test. The necessity for accurate measurements of the steel temperature in determining the flowing qualities of the steel was demonstrated in preliminary trials in the laboratory with the mold of new design. Optical pyrometer readings taken by sighting on the surface of the steel bath were far from satisfactory. Therefore, a method was adopted whereby temperatures at the bottom of a clay-graphite, closed-end tube immersed in the steel could be read with an optical pyrometer.

INTRODUCTION

1. A test method for determining the flowability of cast steel, that would be applicable under foundry operating conditions to metal in the ladle, was the basis for an investigation covering both experimental and plant trials. Several investigators in the past conducted tests in an endeavor to arrive at reliable figures on the flowing qualities of cast steel while it was still in the furnace. These tests have given indications of being suitable for judging the flowing characteristics of a given steel just prior to tapping. In this investigation, it was intended to extend these studies to a measurement of the flowing qualities of the steel completely refined, deoxidized, and in the ladle ready for casting.

RESUME OF LITERATURE

2. The flowability of cast steel has been the subject of several recent articles, having been dealt with by Ruff[1]* and by various British investigators whose works were published in the second and third reports of the Steel Castings Research Committee, The Iron and Steel Institute[2].

Results with Spiral Test

3. Ruff used the Saeger-Krynitsky spiral test in his earlier work, but, because of poor results with the spiral gated in the normal fashion, he first modified the gating to eliminate the horn, pouring basin, and collecting basin. He finally abandoned the spiral test in favor of a test which measured the flow of steel in a straight cylindrical opening 5 mm. in diameter fed through a simple downgate. The latter method, according to Ruff, enabled an operator, with sufficient experience with the test, to determine the running quality of steel from the furnace by simply withdrawing a spoonful of metal and pouring it in accordance with an established procedure.

4. These investigations were followed by those of the various British investigators who not only used the spiral test, but who also investigated Ruff's method for its practical utility in the foundry as well as for its value in providing information on the flowing qualities of various steels.

5. Andrew, Percival and Bottomley[3] used the spiral test to obtain a definite measurement of the flowability of steels of various compositions and at various temperatures. The measurements

---

*Superior numbers refer to bibliography at the end of this paper.

were obtained with a spiral fed from a pouring basin through a down-gate and collecting basin, the spiral being poured under conditions which could be repeated exactly in every experiment as regards the melting, temperature, and casting of the metal. They covered the effects of carbon, silicon, phosphorous, and manganese. This work was extended to iron-carbon alloys containing varying amounts of copper, nickel, silicon, and chromium in a report by Andrew, Bottomley, Maddocks and Percival[4] in 1938.

6. The spiral test has not yet been developed to a satisfactory point for foundry use. Greaves[5] in discussing the fluidity of steel in relation to methods of manufacture, composition, and temperature of casting commented on the test as follows:

"It is clear from these results (made on pairs of spiral test pieces cast from Tropenas steel and bottom-poured from a ladle containing approximately 25 cwt. (2800 lb.) of metal —insertion by authors) that a spiral test carried out in this way is unsuitable as a measure of fluidity. The variation in the results appeared to be mainly due to the manner in which the nozzle of the ladle was opened and shut.

" . . . In none of the foundry tests could the behavior of the steel be associated with a steady fall in temperature due to cooling. From these results, it appears that, in accurate measurements of fluidity with a spiral test-piece, extreme care has to be taken to fill the mold at a definite rate and under a constant head of metal. This is a matter of great difficulty in the foundry, and yet it is clear that without this precaution tests are useless."

7. The method originally proposed by Ruff, with slight modifications, has been tried by various members of the Steel Castings Research Committee with the view of determining if the method could be relied upon to test the steel for fluidity while it was still in the furnace. Their results were, on the whole, encouraging. Greaves[6], for example, was reported to have had results which indicated that consistent values for length of flow could be obtained in dry sand molds if precautions were taken to duplicate handling of the spoon during casting. He immersed the spoon in the steel for 5 sec. before the sample was withdrawn. Walker[7] conducted tests on basic, electric-arc-furnace steels by removing, with a spoon dipped into the bath until warm, a sample taken from a spot half way between one electrode and the edge of the bath. The slag was

removed quickly from the surface of the steel with a wooden stick, the spoon permitted to rest on a metal support similar to that used by Ruff, and the steel poured at a uniform rate into the pouring funnel of the mold. Steel temperatures are difficult to read under these conditions, however, and the figures given are admittedly comparative only. In spite of the difficulties involved in reading temperatures, Walker concluded that "the results so far obtained offer some promise that this type of test will ultimately prove valuable in ensuring that a given cast of steel is made suitable for foundry purposes before being tapped and sent into the foundry."

8. The fluidity-temperature relations of cast steels of various compositions were also critically studied by Sarjant and Middleham[8] using a modified Ruff mold. Their investigations covered both experimental trials on steels cast under closely controlled conditions as regards temperature and pouring of the metal, and shop trials conducted under normal conditions of foundry practice. Regarding the results of the shop trials, these investigators concluded that the method had the necessary simplicity and convenience for industrial purpose to give valuable information on the running characteristics of a steel for a given casting operation.

Factors Influencing Steel Flowability

9. Some of the pertinent factors upon which the measurement of flowability of cast steel depend, as disclosed in the various investigations mentioned, are enumerated briefly in the following paragraph.

10. The test for flowability is one of measuring the distance traversed by a stream of metal in a given size channel before coming to rest as a result of solidification. The length of rod obtained, therefore, represents a summation effect of the running qualities of the metal at all temperatures between that of casting and that of solidification. Temperature, particularly the temperature range through which the metal cools while it is flowing in the test mold, is apparently the all important factor, while composition of the metal and its viscosity play only a minor part. Turbulence in the molten steel is a factor that may be more important than might be suspected. It was found that the tendency for molten steel to change from a state of smooth flow to one of turbulent flow sets in at a lower velocity than for water or for molten malleable cast iron. The effect of turbulence would limit the length of flow to something else than would be expected from increased metal

velocities. This is a further reason for filling the mold at a definite rate and under a constant head of metal. Reproducibility in the flowability results depends upon a standard pouring procedure, the accurate measurement of temperature and the use of molds which are alike in their nature and properties. No difference in the functioning of the Ruff test could be detected on using rod diameters of 0.25, 0.197 and 0.1875-in. or 6.35, 5.0, and 4.76 mm. respectively. Factors of great importance as regards the behavior of steel in the mold are its surface tension, the character of its surface oxide films, the nature of its suspended inclusions and the surface character of the mold.

SCOPE OF INVESTIGATION

11.   The investigation comprised three major divisions as follows:

(1)   The determination of the flowability of various compositions of steel using a method essentially that proposed by Ruff.

(2)   The design of a mold, applying the principles of the Ruff method for measuring the flowability of steel in the ladle.

(3)   Laboratory and foundry trials using the new mold design.

FLOWABILITY OF VARIOUS COMPOSITIONS OF STEEL

Laboratory Test Mold

12.   The choice of the Ruff method for measuring the flowability of steel was prompted by its apparent simplicity from the molding and casting standpoint, by the ease with which flow channels of accurate dimensions could be had and by the possibility of eliminating to a marked degree some of the objectionable features of the spiral method. The Ruff mold was modified in this investigation to provide duplicate rods from the same pour and to allow better control of the rate of pouring and of the height of head. The details of the flowability test mold are shown in Fig. 1.

13.   The two flow channels 7/32-in. in diameter were spaced 1-in. apart. They were flared with a 1/4-in. radius at their entrance into well "B" (Fig. 1) in the desire to lessen turbulence of the steel entering the channels as well as to minimize the tendency for the steel to cut the mold at these points. Chromium plated drill
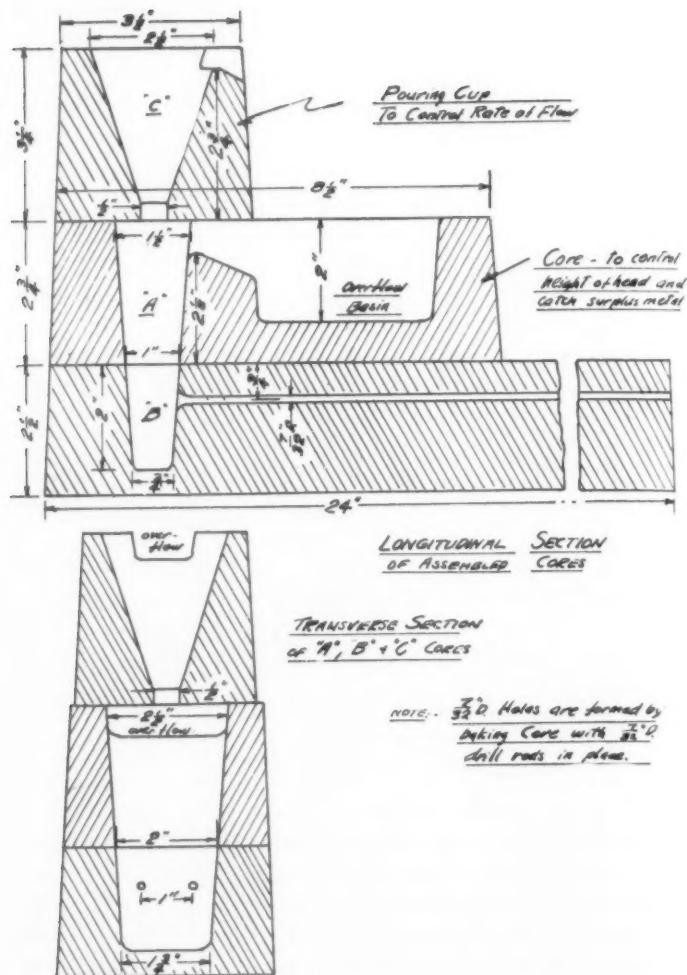
FIG. 1—DETAILS OF THE FLOWABILITY TEST MOLD.

rods, 7/32-in. in diameter, were baked in the core and removed after baking to ensure smooth channels of accurate dimensions. Care was taken in assembling the cores for a test to see that the channels were horizontal and in the same horizontal plane, that the head and well of cores "A" and "B" (Fig. 1) were matched and that the pouring cup "C" delivered the steel into the center of the head.

14. The cores were prepared of baked oil-sand mixtures having the following proportions:

    80 lb. Illinois Sand. A.F.A. Fineness No. 47
     4 lb. Silica Flour
     3 oz. Cereal Binder
     2 pints Core Oil
     4 to 5 per cent Moisture
   243 Dry Permeability

Melting Procedure

15. The steels were prepared in a magnesia lined, converter type, high-frequency induction, electric furnace in 14-lb. batches which brought the surface of the melt to from 2 to 2½-in. from the top of the furnace. The charges were made from the same lot of steel punchings analyzing 0.16 per cent carbon, 0.72 per cent manganese, 0.14 per cent silicon, 0.015 per cent phosphorus and 0.034 per cent sulphur and the necessary ferroalloys, graphite, and copper. The graphite, 0.10 per cent silicon, and copper, when used, were introduced with the initial charge. Following the melt down, temperature observations were made until the temperature was approximately 20 to 50°F. below the desired tapping temperature when the deoxidizers were added. The ferroalloys comprised high carbon ferromanganese, 75 per cent silicon grade ferro-silicon, and medium carbon ferrotitanium. The time from the addition of the ferroalloys until tapping varied from 1 to 5 min., depending upon the temperature desired and the amount of ferroalloys added. The heats were not poured until three temperature readings taken in rapid succession did not vary by more than a few degrees.

Measurement of Temperature

16. An optical pyrometer, having a scale calibrated for an emissivity factor of 0.40, was used so as to give readings corrected for molten steel. The pyrometer was checked each day against a standard lamp.

17. Reading of the temperature of the steel was by far the most troublesome factor to control. To standardize temperature measuring conditions, the furnace was covered with a 1-in. thick kaolinite insulating brick having a 1-in. hole in the center so that one could look directly on the surface of the steel in the center of the furnace. After the ferroalloys were added and stirred in, a
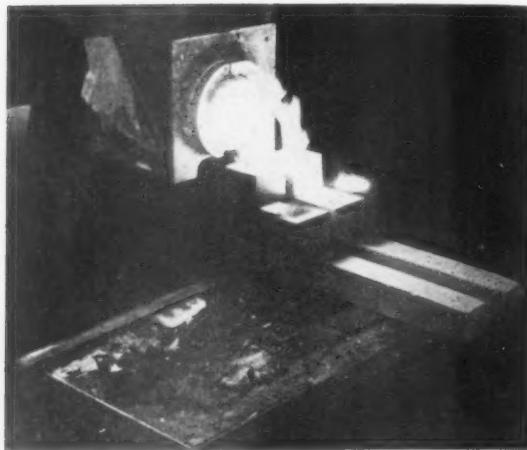
FIG. 2—POURING A FLOWABILITY TEST MOLD.

light covering of periclase was placed on the melt. It was added sparingly and was used to keep the central portion of the surface of the melt from slagging over and to decrease fuming. The pyrometer was focussed at a given spot in the furnace. By observing the above precautions and with the absence of slagging and fuming, it was possible to obtain duplicate or triplicate temperature readings within a 10°F. range. Because the emissivity value for the steel observed under these conditions may not conform to the generally accepted value of 0.40, the temperatures recorded were considered apparent rather than true temperatures.

Pouring Procedure

18.   Experience with the flowability test in preliminary trials, indicated that the first metal issuing from the furnace was likely to give erratic results owing to its being chilled by the cold furnace lip. To avoid the influence of the cold lip, about $4\frac{1}{2}$-lb. of steel was poured into a small iron mold before pouring two flowability test molds in rapid succession. This method of pouring avoided much loss in steel temperature and provided duplicate sets of test rods which usually agreed closely in their length. One heat was used for each temperature. A photograph of a heat being poured is shown in Fig. 2.

Flowability Results

19.   A summary of data on flowability of a number of steels is given in Table 1.

20. The average lengths of flow with temperature for the individual steels are plotted in Figs. 3 and 4 and in composite diagrams in Figs. 5 and 6. Straight lines were drawn since this type of curve showed quite accurately the trend in flowing qualities over the range of temperature investigated. In a few cases, the points were scattered primarily as a result of difficulty in the reading of steel temperatures.

21. Except for the curves for the titanium treated steels, the curves run more or less parallel and have the same slope in the 0.21-0.24 and the 0.29-0.35 per cent carbon grades. Copper and silicon, and combinations of these elements, according to these tests, increase the flowability. Small additions of titanium to manganese-silicon-copper steel definitely increase the slope of the curves, indicating that titanium is deleterious in its effect on flowability of this grade of steel at high metal temperatures.

22. As a matter of interest, it may be recalled that the influence of aluminum on the flowability of grade B type cast steel,
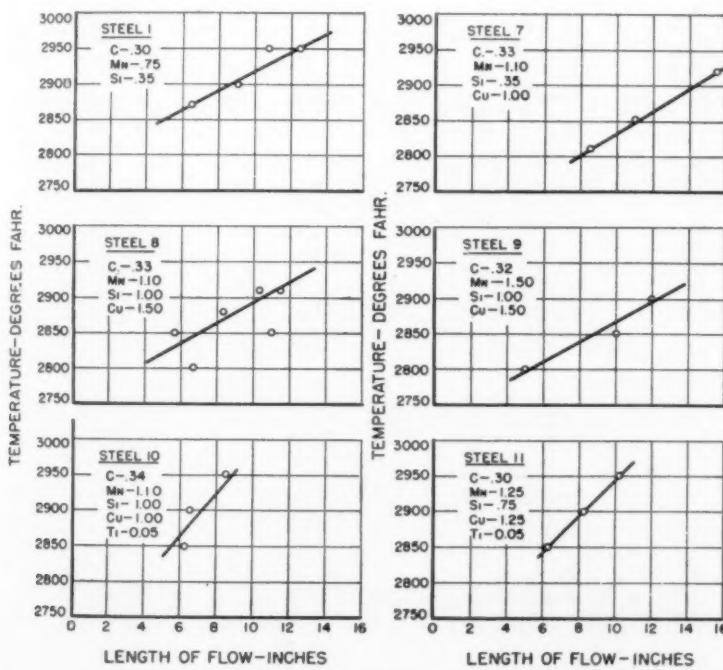
FIG. 3—TEMPERATURE—LENGTH OF FLOW DIAGRAMS FOR VARIOUS 0.29-0.35 PER CENT CARBON CAST STEELS.

Table 1

CHEMICAL COMPOSITION AND LENGTH OF FLOW OF STEELS TESTED

Steel No.	C	Mn	Si	P	S	Cu	Ti (added)	Temp. °F.	Flowability Data — Length of Test Rod — In.				
									Rod 1	Rod 2	Rod 3	Rod 4	Avg.
1A	0.31	0.67	0.35*	0.013	0.028	....	....	2900	8¼	8¾	9	10¼	9
B	0.29	0.75*	0.35*	0.014*	0.03*	....	....	2870	6	6¾	6½	7	6½
C	0.31	0.73	0.35*	0.014*	0.03*	....	....	2950	8	11¾	10¾	12½	10¾
D	0.30	0.75*	0.38	0.014*	0.03*	....	....	2950	10¼	13¼	14¼	13	12½
2A	0.22	1.12	0.35*	0.014*	0.03*	1.0	....	2860	6½	7	6¼	6½	6½
B	0.22	1.10*	0.34	0.014*	0.03*	1.0*	....	2920	11¼	10½	7¼	9	9½
C	0.23	1.10*	0.35*	0.014*	0.28	1.0*	....	2970	14	15	13½	13	13¾
3A	0.23	1.16	1.0*	0.014*	0.03*	0.98	....	2900	11	11½	8¾	9¼	10
B	0.22	1.10*	1.01	0.014*	0.03*	1.0*	....	2850	8¾	11	7	8½	8¾
C	0.23	1.10*	1.0*	0.013	0.03*	1.0*	....	2960	16½	15½	11½	14½	14½
4A	0.21	1.11	1.0*	0.014*	0.03*	1.35	....	2850	7½	7½	6½	6	6¾
B	0.23	1.10*	0.99	0.014*	0.03*	1.50*	....	2900	14¼	14	10	8	11¾
C	0.21	1.10*	1.0*	0.014*	0.27	1.50*	....	2950	16¼	13½	11	17¼	14½
5A	0.22	1.11	1.0*	0.014*	0.03*	1.0	0.05	2900	10½	9	10½	9½	9¾
B	0.23	1.10*	1.01	0.014*	0.03*	1.0*	0.05	2850	7¼	7¼	8¾	9¼	8½
C	0.24	1.10*	1.0*	0.014*	0.03	1.0*	0.05	2950	12	12	12¼	11¼	12
6A	0.22	1.44	0.35*	0.014*	0.03*	1.0*	....	2860	9	9¾	8	9½	9
B	0.22	1.50*	0.33	0.014*	0.03*	1.0*	....	2900	8½	7¼	10	11	9¼
C	0.23	1.50*	0.35*	0.014*	0.03	1.0*	....	2960	14½	15½	13	13½	14
D	0.22	1.50*	0.35*	0.016	0.03*	1.0*	....	2900	8	8½	8¾	8½	8½
E	0.21	1.50*	0.35*	0.014*	0.03*	0.95	....	2860	6¾	7½	5¼	6½	6½
7A	0.33	1.20	0.35*	0.014*	0.03*	1.0*	....	2850	9¾	11½	11	11¾	11
B	0.33	1.10*	0.35	0.014*	0.03*	1.0*	....	2810	7	9¼	8½	9¼	8½
C	0.33	1.10*	0.35*	0.014*	0.03*	1.0	....	2920	15¾	16½	13¼	16½	15½

Table 1 (Continued)

| Steel No. | Chemical Composition, Per Cent | | | | | | | | Flowability Data — Length of Test Rod — In. | | | | |
	C	Mn	Si	P	S	Cu	Ti (added)	Temp. °F.	Rod 1	Rod 2	Rod 3	Rod b	Avg.
8A	0.32	1.16	1.0*	0.014*	0.03*	1.5*	....	2910	11½	12½	10	12½	11½
B	0.33	1.10*	1.03	0.014*	0.03*	1.5*	....	2850	11½	11½	11	10	11
C	0.33	1.10*	1.0*	0.014*	0.028	1.5*	....	2800	6	7½	7¼	6¼	6¾
D	0.33	1.10*	1.0*	0.014	0.03*	1.5*	....	2910	9¼	10¼	9¾	11¼	10¼
E	0.32	1.10*	1.0*	0.014*	0.03*	1.48	....	2850	4	4¾	7	6¾	5¾
F	0.32	1.14	1.0*	0.014*	0.03*	1.5*	....	2880	8	8½	8½	8	8½
9A	0.29	1.42	1.0*	0.014*	0.03*	1.44	....	2800	5¼	6	3¾	4½	5
B	0.33	1.50*	1.0	0.014*	0.03*	1.50*	....	2850	9¾	8¾	10¼	10¾	10
C	0.33	1.50*	1.0*	0.014*	0.027	1.50*	....	2900	11½	13	11¼	11¾	12
10A	0.35	1.14	1.0*	0.014*	0.03*	1.01	0.05	2850	6¼	5½	6	7¼	6¼
B	0.35	1.10*	1.05	0.014*	0.03*	1.0*	0.05	2900	5½	6	8	7	6½
C	0.33	1.10*	1.0*	0.014*	0.03*	1.0*	0.05	2950	7½	8¾	9	9	8½
11A	0.31	1.33	0.75*	0.015	0.03*	1.25*	0.05	2850	6	6½	6	6¾	6¼
B	0.30	1.25*	0.74	0.014*	0.03*	1.25*	0.05	2900	7¼	7½	9¼	9½	8¼
C	0.29	1.25*	0.75*	0.014*	.028	1.25	0.05	2950	9½	10½	11¼	10½	10½
12A	0.22	1.13	0.35*	0.014*	0.03*	....	....	2860	6¼	5½	7½	6¼	6½
B	0.23	1.10*	0.33	0.014*	0.03*	....	....	2910	7¼	9¼	9¼	8½	8½
C	0.21	1.10*	0.35*	0.014*	0.03	....	....	2960	13	13	13	13	13
13A	0.21	1.16	1.0*	0.014	0.03*	....	....	2920	10½	10½	8½	9¼	9¾
B	0.22	1.10*	1.0	0.014*	0.03*	....	....	2850	5	5¾	4¼	6	5¼
C	0.22	1.10*	1.0*	0.014*	0.03	....	....	2970	16	16¼	15¾	16	16

NOTE: Figures followed by asterisk are desired values. All others, with the exception of those for titanium, are determined values. Rods 1 and 2 poured in same core. Rods 3 and 4 poured in same core.
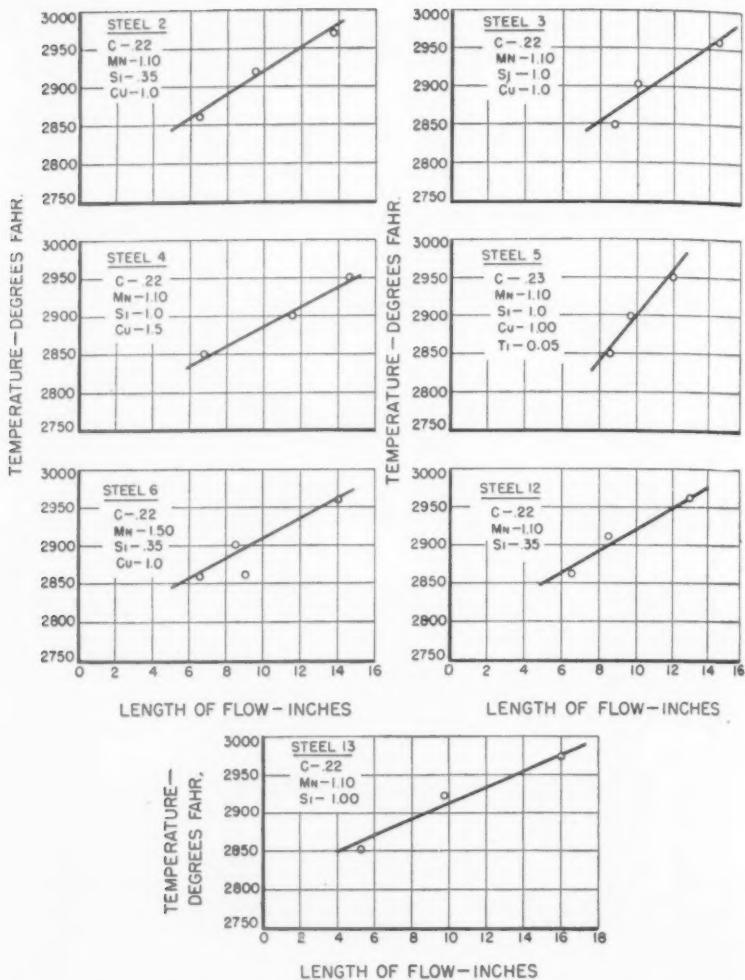
FIG. 4—TEMPERATURE—LENGTH OF FLOW DIAGRAMS FOR VARIOUS 0.21-0.24 PER CENT CARBON CAST STEELS.

determined with the same technique and type of test cores as were used in the above experiments, was shown by Sims and Dahle[9] in the discussion of their paper before this Association in 1938.

23.   The laboratory flowability results obtained with the modified Ruff mold were sufficiently encouraging to warrant the belief that the test could be carried out in the foundry to give a comparatively reliable measurement of the flowing quality of steel, pro-
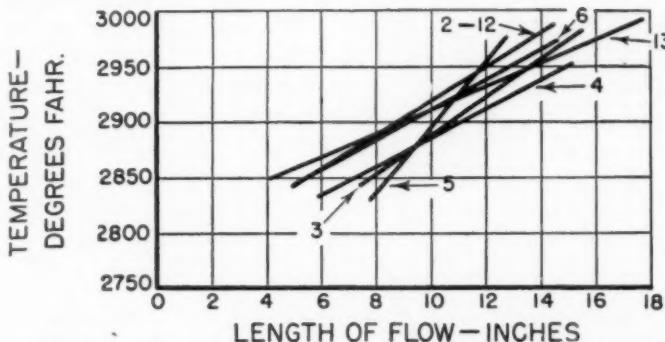
FIG. 5—COMPOSITE OF TEMPERATURE—LENGTH OF FLOW DIAGRAMS FOR VARIOUS 0.21-0.24
PER CENT CARBON CAST STEELS.

vided the necessary precautionary measures as to steel temperature
measurements and reproducibility in casting practice could be
established.

24.   The modified Ruff mold used in the laboratory test was
found to be impractical in the foundry for testing steel in the ladle.
The small quantity of steel needed to fill the mold made it impos-
sible to pour without having the steel chilled by the colder ladle
lip or nozzle. This factor made the test results meaningless. There-
fore, a new design of mold, retaining the principles of the modified
Ruff method, was evolved.

DESIGN OF TEST MOLD FOR FOUNDRY PURPOSES

25.   A detail drawing of the new test mold is shown in Fig. 7.
Fig. 8 shows a photograph of the mold unassembled and Fig. 9,
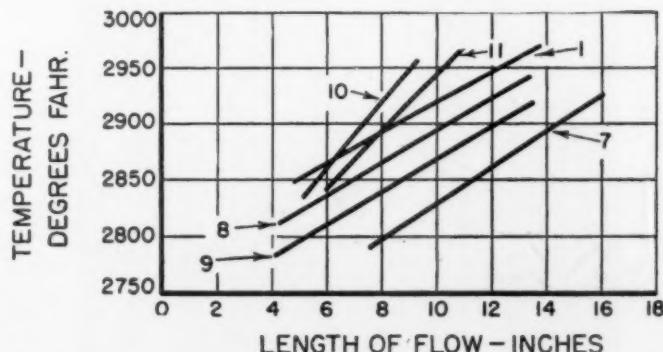
FIG. 6—COMPOSITE OF TEMPERATURE—LENGTH OF FLOW DIAGRAMS FOR VARIOUS 0.29-0.35
PER CENT CARBON CAST STEELS.
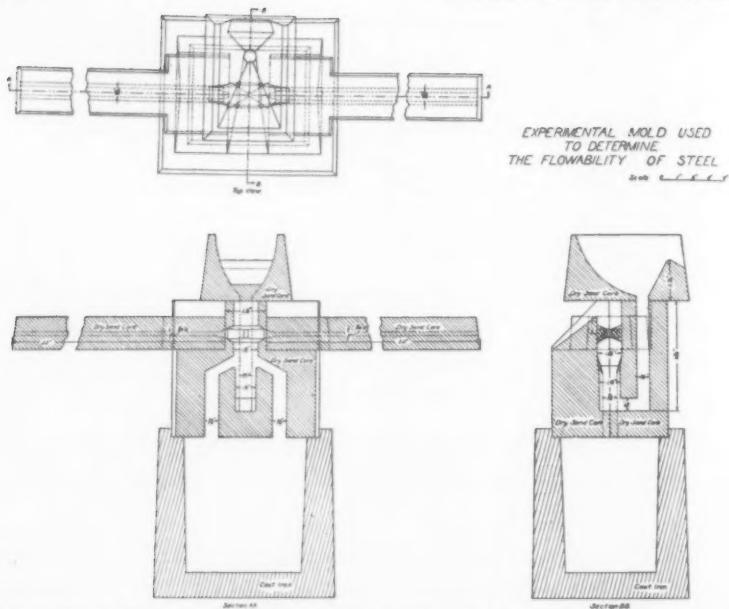
FIG. 7—DETAIL DRAWING OF EXPERIMENTAL MOLD USED TO DETERMINE THE FLOWABILITY OF STEEL IN FOUNDRY TRIALS.

assembled in position for pouring. This mold was designed to reduce the effects of metal head, turbulence, and inertia, and to maintain a uniform rate of pouring.

26.   To ensure that the metal filling the test rods is at the temperature of the metal being tested, provision is made for running off the first 100-lb. of steel entering the mold. To control the
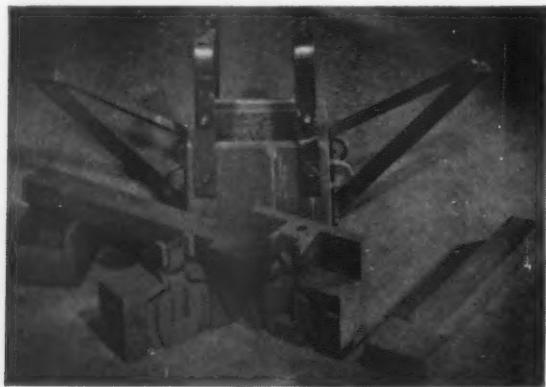
FIG. 8—PHOTOGRAPH OF THE UNASSEMBLED MOLD SHOWING THE DRY SAND CORES AND CAST IRON RECEPTACLE.

static head of metal, a run-off is placed at a definite height above
the test rods. This open run-off also served to prevent the building
up of inertia pressure which would result were the flow of metal
suddenly checked. The possibility for turbulence is reduced by hav-
ing a straight central head several times as long as its greatest
cross sectional dimension for feeding the test rods and which has
an area considerably larger than that of the down-sprue. A uniform
rate of flow in the central head is maintained by having a constant
head in a down-sprue of fixed cross section.

27. A large cast iron receptacle with a holding capacity of
about 100-lb. of steel serves as a base for the mold. A split, dry-
sand core is set into a recess in the cast iron receptacle. This core
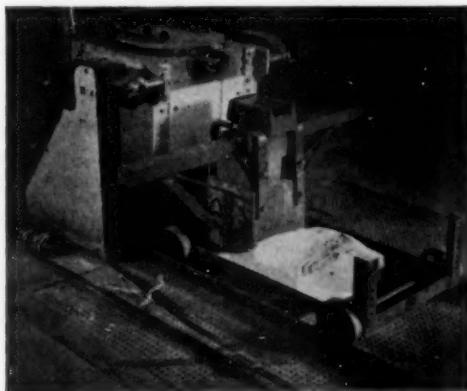
Fig. 9—Photograph of the Assembled Mold Showing the Mold in Position
for Pouring.

contains a $\frac{3}{4}$-in. sprue, two $\frac{7}{8}$-in. overflow channels that discharge
into the cast iron receptacle, and a $1\frac{1}{4}$-in. square section, central
head. The central head, above the junction of the $\frac{7}{8}$-in. overflow
channels, increases to $1\frac{1}{2}$-in. square. Two horizontal, dry-sand
cores, each having two, 7/32-in. diameter channels spaced $\frac{3}{4}$-in.
apart in which the test rods are formed, engage into recesses in the
split core so that the 7/32-in. channels register with openings in
the $1\frac{1}{2}$-in. section of the central head. Above the sprue is a dry-
sand pouring basin with an overflow to control the height of metal
during pouring. The various parts of the mold are securely clamped
and leveled prior to pouring.

28. The height to which metal can rise in the central head of
the split core is limited by the run-off which is 1 in. above the

central axes of the test rods. Two small projections in the central head, at the openings into the four test rod channels, maintains a uniform flow of metal in the head and assists in deflecting the metal into the test channels.

29.   The flow of the steel through the mold is as follows: It passes from the pouring basin through the sprue and gate into the central head where it rises until it overflows into the cast iron receptacle. When the receptacle is filled, the steel rises further in the central head, fills the test channels and finally discharges over the run-off. Normally about 30 sec. are required to fill the mold, but with cold metal, the time may be as much as 40 sec. This length of time is sufficient to adjust the pouring rate so that the pouring head is constant when the test rods are cast.

30.   Thus, with the new design of mold, the steel chilled by the cold channels in the mold, the spout of the furnace or the lip and nozzle of ladles, discharges into the cast iron receptacle. Ample steel is drawn off before the test rods are cast to ensure that the temperature of the steel filling the test rod channels is the same as that for the mass of steel being tested.

LABORATORY TEST RESULTS USING NEW MOLD DESIGN

Melting and Pouring Practice

31.   Steels for laboratory tests were prepared in a magnesia lined, motor-generator-type, high-frequency induction, electric furnace in heats weighing 120 lb. from charges of ingot iron, graphite and the necessary ferroalloys and alloying elements.

32.   The mold assembly was mounted on a small truck and leveled to bring the four test rod channels into the same horizontal plane (Fig. 9). Steel was poured directly from the furnace into the mold with the rate of pouring adjusted manually so as to keep the pouring basin filled up to the overflow. There was no difficulty with controlling the rate of pouring from the furnace since for the particular set up the sprue was of about the proper diameter to maintain a full pouring basin. The 120-lb. heats were large enough to allow for metal overflow at the pouring basin and 5 to 10 lb. in excess of that needed to fill the mold. The entire heat was poured, with the excess steel discharging over the run-off in the split core into a pit below the furnace. Fig. 10 shows a photograph of the test casting with its four test rods.

Measurement of Temperature

33.   Direct reading of steel temperatures, by sighting an optical pyrometer on the surface of the bath, was tried with no success. Simultaneous readings taken with three instruments were occasionally in agreement, but more often differed from 25 to as much as 125°F. Furthermore, at steel temperatures where the surface becomes covered with a film, the emissivity of the surface changes to such an extent that the readings corrected for an emissivity of 0.40 may be in error by as much as 200°F. As a conse-
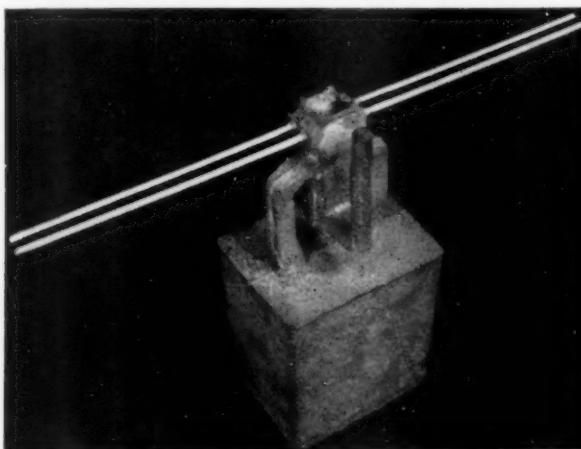
Fig. 10—Photograph of the Casting From the New Design of Mold Showing the Four Test Rods and Gating Arrangement.

quence of these conditions, it was impossible to obtain consistent flowability-temperature values and all results using this method of temperature reading were discarded.

34.   A method for measuring steel temperatures more accurately, that was finally adopted, involved reading the temperature at the bottom of a small closed end, clay-graphite tube immersed a given depth into the bath of steel. The clay-graphite tube was 1-in. in diameter, 8-in. long and had a 3/8-in. bore extending to within 1/2-in. from the bottom. It was mounted at one end of a long narrow frame having an optical pyrometer mounted at the other end. The mounted tube and pyrometer can be seen in the foreground of the photograph, Fig. 9.

35.   The tube was immersed in the steel to a depth of 5-in. About 1/2 to 1 min. was required for it to reach the steel temper-

ature. Temperature readings were recorded as those for black body conditions. The tube life was from 8 to 10 immersions. A close check on the carbon content of the steel before and after immersing the tube showed no measurable difference.

Flowability Results

36.   The flowability data on various steels obtained in the laboratory experiments using the new mold and the above described method for determining temperatures are summarized in Table 2 and in Fig. 11.

37.   Along with the curve for steel 14, is the curve for steel 1 taken from Fig. 3. These curves represent values secured on the same type of steel using the small modified Ruff mold and the mold of new design. The results do not agree. It is suspected from the slope of its curve, and from comparisons which were made of the two molds using other grades of steel, that the lack of agreement was due mainly to errors in or to unknown factors that affected the
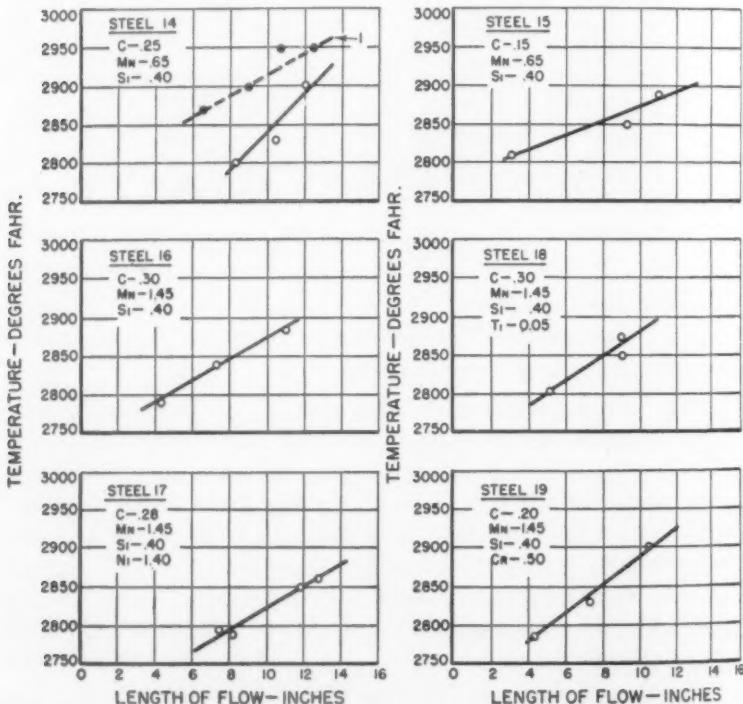
FIG. 11—TEMPERATURE—LENGTH OF FLOW DIAGRAMS FROM DATA ON VARIOUS CAST STEELS MADE IN THE LABORATORY USING NEW TEST MOLD DESIGN.

Table 2

CHEMICAL COMPOSITION AND LENGTH OF FLOW OBTAINED ON CAST STEELS USING NEW MOLD DESIGN

(Laboratory Trials)

Steel No.	C	Mn	Si	Ni	Cr	Ti (added)	Temp. °F.	Flowability Data — Length of Test Rod — In.				
								Rod 1	Rod 2	Rod 3	Rod 4	Avg.
14A	0.25	0.65	0.40*	...	...	...	2800	8⅜	7½	8⅜	8⅝	8¼
14B	0.28	0.64	0.40*	...	...	...	2830	10½	9¾	10⅝	10⅝	10⅜
14C	0.24	0.63	0.40*	...	...	...	2900	12	11½	11⅛	13⅜	12
15A	0.11	0.63	0.40*	...	...	...	2810	3	3¾	3⅜	1⅞	3
15D	0.15	0.66	0.40*	...	...	...	2875	9⅜	8¾	9¾	9	9¼
15C	0.17	0.62	0.40*	...	...	...	2890	10¾	10⅝	11⅜	12	11⅜
16F	0.30	1.46	0.40*	...	...	...	2792	4¼	4⅝	4	4¾	4⅞
16G	0.27	1.50	0.40*	...	...	...	2840	7¼	7	6¾	7¾	7
16H	0.31	1.40	0.40*	...	...	...	2885	10¾	10¾	11⅜	11⅜	11
17B	0.27	1.48	0.40*	1.40*	...	...	2780	8⅞	8¼	8¼	8¼	8⅜
17A	0.26	1.50	0.40*	1.40*	...	...	2795	7½	7¼	7⅞	7⅞	7½
17C	0.28	1.38	0.40*	1.40*	...	...	2850	12½	11¼	11½	12¼	11⅞
17D	0.33	1.39	0.40*	1.40*	...	...	2860	12¼	12¾	12¾	13¼	12¾
18A	0.28	1.50	0.40*	...	...	0.05	2820	5¼	5¾	5	5⅝	5⅛
18B	0.32	1.39	0.40*	...	...	0.05	2850	10⅛	8⅝	8¼	9	9
18C	0.30	1.42	0.40*	...	...	0.05	2880	8¾	8⅝	9¼	9¼	9
19A	0.19	1.50	0.40*	...	0.50*	...	2785	4¼	4⅛	4½	4½	4⅜
19B	0.21	1.39	0.40*	...	0.50*	...	2830	7¼	5⅞	7¾	8¼	7¼
19C	0.29	1.45	0.40*	...	0.50*	...	2900	10¾	10¾	11¼	9⅞	10½

NOTE: Figures followed by asterisk are desired values, all others, with the exception of those for titanium, are determined values. 120-lb. Heats. Four rods to a casting.

testing of steel 14. In other comparative tests involving medium manganese, manganese-nickel and manganese-titanium steels, the temperature-length of flow curves were parallel and did not differ by more than 25°F.

PLANT TEST RESULTS USING NEW MOLD DESIGN

38.   Experiments with the new mold design were conducted in the foundry using grade B type, basic open-hearth steel prepared in heats of 27 tons and cast from a bottom poured ladle. Steel temperatures reported are the average of six or seven values read with an optical pyrometer sighted on the stream from the nozzle. This method of measuring steel temperatures is not entirely satisfactory, but, under the conditions of testing, it was the most practical method available.

39.   Some changes in the dimensions of the sprue, the overflow channels and the central head were necessitated by the high pressure of the steel entering the mold and by the large amount delivered when the 1¾ or 2-in. nozzle was opened. Molds similar in dimensions to those used in the laboratory were unsatisfactory. The sprue was not large enough in diameter to empty the pouring basin as rapidly as the steel entered even though the flow of steel from the ladle was restricted with the stopper. A ⅞-in. diameter sprue was finally adopted, though it might easily be enlarged still more to reduce spillage and to shorten the time for pouring. Likewise, the overflow channels leading into the cast iron receptacle were small and were later increased from ⅞-in. square to 1-in. by 1½-in. in section. The initial rush of steel into the mold on opening the nozzle sometimes caused the steel to rise higher in the central head than the openings into the test rod channels, spoiling the test. To overcome this difficulty, the partitions between the central head and the two overflow channels were reduced 1 in. in height and the bottom of the central head between the partitions was enlarged to 1½-in. square. With these changes in dimensions, test rods were poured from several heats of steel. The results are summarized in Table 3.

40.   Two test molds were set up on the foundry floor so as to be poured at intervals during the casting of a heat. The first mold was poured after 6 tons, and the second mold, in the case of steels 20, 21, and 22, was poured after 21 tons of steel had been cast. For steel 23, the molds were poured in consecutive order after 6 tons of steel were run from the ladle. The interval of time between pour-

Table 3

CHEMICAL COMPOSITION AND LENGTH OF FLOW OBTAINED ON CAST STEEL USING NEW MOLD DESIGN IN FOUNDRY TRIALS

Steel No.	Chemical Composition, Per Cent					Temp. °F.	Flowability Data — Length of Test Rod — In.				
	C	Mn	Si	Preliminary C	Residual Mn		Rod 1	Rod 2	Rod 3	Rod 4	Avg.
20A	0.27	0.69	0.38	0.21	0.27	2930	9⅝	9½	8	8¾	8⅞
20B						2800	3½	3⅜	3⅜	3⅜	3½
21A	0.27	0.68	0.35	0.145	0.29	2870	3⅜	3¾	3¼	3¼	3⅜
21B						2810	3⅝	3½	3⅞	3⅜	3½
22A	0.27	0.72	0.39	0.18	0.28	2900	2⅞	2¼	2⅝	2¾	2⅝
22B						2800	1¾	1¾	2	2⅞	1⅞
23A	0.29	0.71	0.37	0.20	0.28	2900	7¾	7¾	7¾	9⅜	8
23B						2900	8⅛	7⅞	7	7¼	7½

ing of the two molds for the first three steels was somewhat more than ½-hr., during which period the temperature of the steel dropped from 60 to 130°F. The time for pouring each mold was from 20 to 25 sec.

41.   Tests on steel 20 were carried out with satisfaction, and the length of flow obtained was more or less in line with laboratory results on the same type of steel. The performance of the molds during the testing of steel 21 also was satisfactory. Nevertheless, the results at 2870°F. were most surprising as the rod lengths were less at this temperature than at 2810°F. While the reason for this was not obvious, excluding possible errors in testing, certain factors in the making of the steel may have contributed towards its low flowability at 2870°F. The heat, as shown by the preliminary carbon analysis, finished low in carbon and was recarburized in the ladle with enough coke to raise the carbon content 0.07 per cent. The remainder of the carbon, of course, was introduced with the ferroalloys. The combination of circumstances, resulting in the low preliminary carbon content and the necessity for recarburizing with coke, may have adversely affected the flowability of the steel during the early part of cast. The possibility for lower flowability under these conditions is not without some basis as some foundrymen feel that recarburized steel is less fluid than steel which requires no recarburizing with coke. The fact that the steel at 2810°F. shows the same flowability as steel 20 at 2800°F. is interesting. Presumably the influence of recarburizing, if it is deleterious to flowability, disappears on holding the steel in the ladle.

42.   In testing steel 22 at 2900°F., the nozzle was opened too rapidly at the start and, as the steel entered the first mold, it rose above the openings for the test rods before a steady flow was obtained. Therefore, the test results for this mold were of no value. In pouring the second mold, it was difficult to obtain a satisfactory temperature reading so that the temperature of 2800°F. recorded for this test is questionable. This heat also was recarburized with a small amount of coke in the ladle.

43.   The result of the test on steel 23 compares with that for steel 20.

44.   From results in the foundry, it is evident that the method of testing shows a reasonable relationship between the temperature and the flowing qualities of the steel. These foundry trials show the method of testing to be simple, practical and adaptable for foundry

use. Naturally, the mold design can be improved. Yet with close control of all details connected with the test, with good pouring technique and with accurate reading of the temperature of the steel, all essential factors in making the test successful, the mold described appears to have the necessary attributes for obtaining a reliable index of the flowing qualities of steel in the foundry.

Acknowledgment

45. The authors acknowledge their indebtedness to D. E. Krause for his aid in conducting the laboratory tests with the small modified Ruff mold and to the Buckeye Steel Castings Co., Columbus, Ohio, for their cooperation and assistance in carrying out the foundry trials.

Bibliography

1—Ruff, W., *"The Running Quality of Liquid Malleable Iron and Steel,"* IRON AND STEEL INSTITUTE, Carnegie Scholarship Memoirs, vol. 25, 1936, pp. 1-39.

2—The Iron and Steel Institute, SPECIAL REPORT NO. 15, SECOND REPORT OF THE STEEL CASTINGS RESEARCH COMMITTEE, 1936, pp. 26 to 64; SPECIAL REPORT NO. 23, THIRD REPORT OF THE STEEL CASTINGS RESEARCH COMMITTEE, 1938, pp. 5-60.

3—Andrew, J. H., Percival, R. T., and Bottomley, G. T. C., *"The Fluidity of Iron—Carbon and other Iron Alloys,"* IRON AND STEEL INSTITUTE, SPECIAL REPORT NO. 15, 1936, pp. 43-64.

4—Andrew, H. J., Bottomley, G. T. C., Maddocks, W. R. and Percival, R. T., *"The Fluidity of Alloy Steels,"* IRON AND STEEL INSTITUTE, SPECIAL REPORT NO. 23, 1938, pp. 5-34.

5—Greaves, R. H., *"Fluidity of Steel in Relation to Method of Manufacture, Composition, and Temperature of Casting,"* IRON AND STEEL INSTITUTE, SPECIAL REPORT NO. 15, 1936, pp. 26-42.

6—Greaves, R. H., *"Introductory Comments on the Ruff Test,"* IRON AND STEEL INSTITUTE, SPECIAL REPORT NO. 23, 1938, p. 34.

7—Walker, T. R., *"Works Results Using the Ruff Fluidity Test,"* IRON AND STEEL INSTITUTE, SPECIAL REPORT NO. 23, 1938, pp. 35-43.

8—Sarjant, R. J. and Middleham, T. H., *"Fluidity-Temperature Relations of Cast Steels of Various Compositions,"* IRON AND STEEL INSTITUTE, SPECIAL REPORT NO. 23, 1938, pp. 45-60.

9—Sims, C. E. and Dahle, F. B., *"Effect of Aluminum on the Properties of Medium Carbon Cast Steel."* TRANSACTIONS, American Foundrymen's Association, vol. 46, 1938, pp. 65-132.

DISCUSSION

Presiding: W. H. SPENCER, Sealed Power Corp., Muskegon, Mich.

N. A. ZIEGLER:[1] What is wrong with the Saeger-Krynitsky spiral test? Does Dr. Lorig have any data on the correlation between the Saeger-Krynitsky test as applied to steels and his own test?

DR. LORIG: We do not have information on the Saeger-Krynitsky spiral test as we had not used it in our work on steel. One of the objections to the method is that using dry sand molds such as are used for steel castings, the cross sectional dimensions of the spiral would probably vary because of the warpage of the cope and drag cores on baking. Furthermore, the idea of feeding the spiral with a horn gate is not the best since it means that the steel flows with an increasing velocity as it approaches the spiral. As it enters the spiral, the steel must take a right-angle turn, another bad feature of the test method.

C. W. BRIGGS[2] (*Written Discussion*): The authors have prepared a very interesting paper on the subject of fluidity of cast steel and I wish to compliment them on the information they have presented.

If I may, I should like to point out some experiences that I have had with fluidity testing of cast steel. The authors refer to the use of the Ruff test at the furnace by several English investigators and suggest that their results were encouraging. I am quite familiar with their published results and, while I agree they are encouraging, I fail to see the superiority of such tests over those possible with the fluidity spiral. I have used the fluidity spiral (a modification of the Bureau of Standards type wherein a straight down gate is used) as a control for the time to add deoxidizers to the furnace and tapping condition for several years, and I can state that the results I obtained regularly were much superior as to checking length of run than those recorded by the English investigators using the Ruff test mold. I do not present this information with the idea of discrediting the Ruff type of test but present it with the idea that if procedure at the furnace is controlled, the Ruff mold is not superior to the fluidity spiral.

Also I am familiar with the work of Sarjant and Middleham and I would like to suggest that anyone who shows fluidity increasing to infinity with increasing temperature has not critically studied the subject.

In regard to the authors' laboratory measurements, I am not going to challenge their figures at this time except to point out two things. At least two melts were necessary to plot the curves. These melts were made as nearly identical as is possible to make them yet I believe it is because of this that their points are somewhat scattered requiring them to draw straight lines thereby showing that fluidity-temperature is a straight line function. This, I believe, is also the reason for the many different slopes obtained even though they are generally in the same direction. The other contributing factor to these conditions is the fact

---

[1] Crane Company, Chicago, Ill.
[2] Steel Founders' Society of America, Cleveland, Ohio.

that they used an optical pyrometer for the determination of tempera-
ture. Regardless of whether the pyrometer is checked daily, variations
in the actual temperature of the metal and that recorded by the pyrom-
eter are obtainable. On some heats, the optical pyrometer will check a
thermo-couple very well and on other heats it will not. At least this
has been my experience and I know that I am not alone in this regard.
This I believe is also a factor contributing to the shape and slope of
the curves.

The authors further state that the static head of metal is con-
trolled by placing a run-off at a definite height above the test rods of
the mold designed for foundry purposes. I should like to ask if they do
not believe that the test channel has been run before the metal enters the
flow off? Not that this makes any material difference in the results
since the tests are all poured under uniform conditions but in such a
small test section, one could point out that the run off is more for con-
venience than for controlling the static head.

The method the authors used shows encouraging results when carried
on under plant conditions on the pouring floor. I presume it is their
idea of being able to test the characteristics of the metal during the
interval of pouring. This would prove most interesting, but if it develops
that there are few changes, since they have in a preliminary way shown
that the foundry values checked those obtained in the laboratory, I see
little advantage for testing for fluidity from the ladle in preference to
making the test at the furnace at tapping time. It is possible that some-
thing may be done to correct steel with poor fluidity while it remains
in the furnace.

I do not wish my remarks to be considered as disparaging to the
authors. Quite the contrary. I know the trials that one experiences when
working with such a difficult subject. Their work is a distinct contribu-
tion and it is quite a privilege to compliment them upon it. The subject
of fluidity is one in which all steel casting men are vitally interested
and I know that they appreciate the efforts of the authors and shall
study their results carefully.

DR. LORIG and MR. KRON: We are grateful for the discussion of-
fered by Mr. Briggs. His remarks are pertinent and focus attention on
those variables that make results of this sort of investigation less exact
than one would desire.

We also would prefer to test the flowability of steel at the furnace
where an adjustment to correct steel with poor fluidity could, seemingly,
be made. It so happens, however, cast steel, whether of plain carbon
or of low alloy variety, frequently is deoxidized and recarburized, as
well as alloyed, in the ladle. In that case, tests on the unfinished steel
in the furnace, in our opinion, would be meaningless, as it is quite
probable that the deoxidizing and recarburizing practices followed have
a significant bearing on the flowing qualities of the steel produced.

MEMBER: I am told that over-reduced steels do not run well and I
would like to know whether the authors found any relation between

flowability and what we might call the state of over-reduction; in other
words, ductility.

DR. LORIG: We did not make any effort to test the flowability of
over-reduced steels. We never encountered over-reduced steels in our
experimental work because we had not tried to make the steel nor were
our plant trials on steels that were over-reduced.

MR. BRIGGS: I would like to make one further comment. I compli-
ment the authors on this work. I know that it is an extremely difficult
proposition to make any type of fluidity test on any of the other alloys,
let alone steel. Their paper has been very interesting to me, as I imagine
it has to most steel men. I think they are doing fine work. I agree with
Dr. Lorig on the proposition of the spiral test in some of its aspects,
as he suggested. I believe by modifications of the Saeger test, you can
obtain very good results with steel but you must modify the pouring
gate, and I would suggest using green sand.

Malleable Iron Castability Tests

BY E. J. ASH,* ANN ARBOR, MICH.

Abstract

A modified type of the Saeger-Krynitsky fluidity mold is described by means of which reproducible results were obtained in white iron. It was found that the fluidity of duplexed, air-furnace iron was improved by deoxidation, and that the fluidity of the metal when remelted in an indirect arc furnace, was impaired by the addition of both deoxidizers or oxide. Fluidity appeared to be at a maximum when a certain amount of oxide was present.

1. In practically all malleable foundries, prior to pouring castings, some type of test is made to determine the flowing power of the metal. These tests may consist of casting a spiral mold such as the Saeger-Krynitsky type, or modifications of this method, or of pouring a casting with a number of small prongs, somewhat analogous to a fork. In some foundries, where experience has shown a direct correlation between temperature and flowing power, only temperature measurements are made, using an optical pyrometer. Temperatures are estimated also by noting the time in seconds required for slag to form on the surface of a spoon or sample of metal. In some foundries, a combination of the above tests are carried out. In all cases, whether the test consists of pouring a mold or measuring temperature, the primary purpose is to determine or estimate the relative ability of the metal to fill the mold properly. This property of metal has been termed flowability, flowing power, fluidity, castability, life, etc.

2. The flowing power of a metal, minus mold conditions, is generally assumed to be a function of the composition and temperature. These factors in turn influence the viscosity and surface tension.

3. Observations made in a foundry producing malleable iron by cupola-air furnace duplexing, indicated that the flowing power of the metal, as measured by the Saeger-Krynitsky method, was not always a function of pouring temperature and composition.

* Associate Professor, Dept. of Metal Processing, University of Michigan.

4.   Data showed that, for a given pouring temperature, the spiral length of irons with practically identical composition, may range from 15 to 22 in. The differences in carbon and silicon content were not sufficient to justify this large variation in spiral length. It was suspected that these variations in flowing power might be attributed to the effect of "minor constituents" in the metal such as oxides.

5.   The purpose of this paper is to describe the variations in the flowing power of duplexed white iron when the amount and form of oxygen is varied by oxidation or deoxidation of the metal just before pouring.

6.   A modified form of the Saeger-Krynitsky fluidity spiral mold (Fig. 1) was used to determine the flowing power of the metal. It will be noted in this figure that the only change involves the manner in which the metal is introduced into the horn gate. A core pouring box is mounted over the down gate, and a ¾-in. core rod is placed over the ½-in. discharge outlet into the down gate. In making a test, the core basin is filled with metal, the ¾-in. core rod is removed immediately, and the metal enters the spiral under conditions that can be duplicated from test to test. Many preliminary tests were made using the original mold design, but the results were so erratic that the present modified design was

FLOWABILITY TEST MOLD
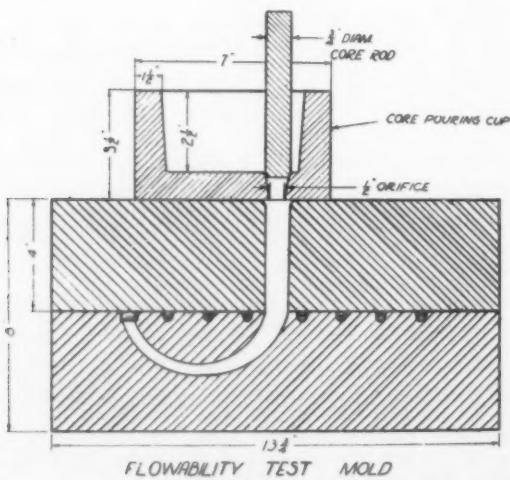
FIG. 1 — CROSS-SECTION OF MODIFIED SAEGER-KRYNITSKY FLUIDITY SPIRAL MOLD USED IN THIS INVESTIGATION.

adopted and used throughout this investigation. Fig. 2 shows
several runs, demonstrating the quality of results obtained by
the modified method as expressed by the smooth curves produced.

Fig. 2 — Curves Showing the Pouring Temperature-Spiral Length Relationships,
Indicating Regularity Obtained Using the Modified Fluidity Design.

7. Temperatures were measured by means of an optical pyrom-
eter, and the observations were made on the metal surface in the
ladle just before pouring the mold. A stock of white iron was
obtained for laboratory studies, from the same heat of metal
(duplexed). Portions of this metal were remelted in an indirect-
arc type rocking furnace to a temperature of 2900°F., and a set of
four molds were poured. A second set of molds then were poured
from the same metal, to which 0.05 per cent of silicon, as ferro-
silicon, was added to the ladle during tapping (deoxidized).
Iron oxide was added to the remaining metal in the furnace, and
after 4 min., a third set of molds were poured (oxidized). The
fourth set of molds were poured from the oxidized metal to which
0.05 per cent of silicon, as ferro-silicon, had been added. The results
of these runs are given in Fig. 3. These heats were duplicated.
The results produced the same trend, but not always in the same
degree.
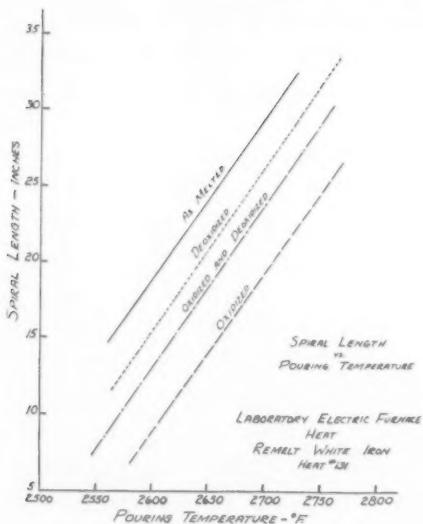
FIG. 3 — CURVES SHOWING EFFECT OF LADLE ADDITIONS TO DUPLEXED IRON REMELTED IN
THE ELECTRIC FURNACE.
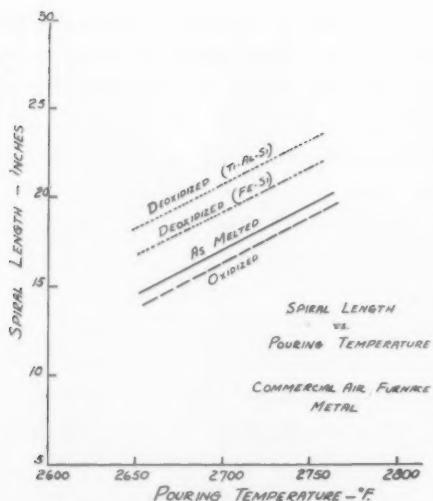
FIG. 4 — CURVES SHOWING EFFECT OF LADLE ADDITIONS TO DUPLEXED AIR-FURNACE IRON.

8. This same procedure was conducted in the plant where the metal was obtained originally. The metal poured was taken from a single bull ladle. Results are shown in Fig. 4. These results were duplicated in subsequent tests.

9. These data, as determined by the above procedure, indicate that for the duplex metal remelted in an indirect-arc furnace and at a fixed pouring temperature:

(1). The addition of deoxidizer (0.05 per cent silicon) to the "as-melted" metal decreased the spiral length $3\frac{1}{2}$ in.

(2). The addition of oxygen (0.1 per cent by weight of Fe_2O_3) decreased the spiral length 10 in.

(3). The addition of a deoxidizer to the oxidized metal improved its spiral length 4 in., yet the length was 6 in. shorter than the as-melted metal.

10. In general, all additions decreased the flowing power of the metal.

Results Obtained on Air Furnace Metal

11. Additions to the air furnace metal showed the following:

(1). The addition of the deoxidizer ferrosilicon improved the spiral length 2 in.

(2). The addition of the deoxidizer titanium-aluminum-silicon improved the spiral length $3\frac{1}{2}$ in.

(3). The addition of oxygen (0.1 per cent by weight of Fe_2O_3) decreased the spiral length $\frac{3}{4}$ in.

12. In general, additions of deoxidizers to commercial air furnace iron improved the flowing power, whereas, the addition of iron oxide reduced the flowing power.

13. In discussing these results, it may be well to consider the observations of other investigators.

Results of Other Investigators

14. It is the general concensus of opinion among cupola operators that oxidized metal is sluggish and lacks fluidity. This opinion is in agreement with observations of this study. Since

duplexed air furnace metal is subjected to oxidizing conditions, this metal is less fluid than the same metal when deoxidized.

15.   The deoxidation did not change the oxygen content of the metal, but it may be assumed that the iron oxide which existed in the bath was converted to another form.

16.   A number of investigators have found that oxide addition to a molten metal increases the surface tension. Most of these references apply to non-ferrous metals. In the work of McCrae, Dowdell and Jordan[1], it was pointed out that a lack of oxygen in the bath produced sluggish metal, while the addition of oxygen in the form of iron oxide immediately (2 min.) improved the flowing power·of the steel. Melmoth[2] has stated that, "fluidity may not be a direct function of temperature and orthodox composition." These latter observations infer that a steel too low in oxides is sluggish.

17.   All of these data, the results of other investigators, and the present work, indicate the probability of maximum fluidity associated with a given oxygen concentration in the bath. This concentration may represent the oxide content forming the eutectic mixture of iron—iron oxide. Higher or lower concentrations of iron oxide would change the running power through change in surface tension.

SUMMARY

18.   The results of this investigation may be summarized as follows:

1.   The Saeger-Krynitsky fluidity design was modified to control the metal entrance into the mold, resulting in greater uniformity of results.

2.   Addition of deoxidizers to duplexed, air-furnace metal improved its fluidity, while iron oxide additions tended to decrease fluidity.

3.   Additional deoxidizers and iron oxide added to re-melted duplexed air-furnace metal, has in all cases decreased fluidity.

¹ McCrae, Dowdell and Jordan, "A Study of the So-called 'Over-reduced' Condition in Molten Steel," NATIONAL BUREAU OF STANDARDS JOURNAL OF RESEARCH, vol. 5, RP250, Nov. 1930, p. 1123.

² Melmoth, F. A., "Some Metallurgical Points in Electric Steel Castings and Notes on Defects," PROCEEDINGS, Institute of British Foundrymen, vol. 19, p. 425 (1925-26).

4. All results indicate a maximum fluidity is associated with a certain oxygen concentration in the bath, probably in the form of iron oxide; higher or lower concentrations tending to decrease the flowing power.

DISCUSSION

Presiding: G. P. HALLIWELL, H. Kramer & Co., Chicago, Ill.

CHAIRMAN HALLIWELL: I was very much interested to see Mr. Ash's attempt to control the head of metal and the surging of metal into the spiral. Last year, I used a similar method and I know that there has been some criticism of it. However, I am glad to see that someone else also is trying that same feature, to get away as far as we possibly can from the personal equation.

N. A. ZEIGLER:[1] I would like to ask Professor Ash about the composition of his metal. We made some castability tests on cupola malleable iron manufactured in our Chicago foundry. Five melts have been made in our 200-lb. laboratory high frequency furnace, using as raw material malleable scrap of general composition: The charge was superheated to 2600, 2700, 2800, 2900, and 3000°F. Each melt was cast

Si.	Mn.	S.	P.	T. C.
%	%	%	%	%
0.91	0.47	0.155	0.17	3.14

into five standard test bar molds, alternately arranged with five spiral Saeger and Krynitsky "castability" molds. The temperature of each heat was checked with an optical pyrometer while still in the furnace, and while pouring each mold. Small amounts of silicon and carbon were added to make up for the losses. The chemical compositions of these melts and of the raw material were nearly the same.

The "castability" data, as affected by the pouring temperature, are represented in Fig. 5. Each point represents the average length of five spirals from each heat, and the average temperature of each heat. It may be noted that scattering of individual points was much more pronounced than in the case of gray iron. Nevertheless, a relationship, represented by a curve, is quite apparent. The maximum castability of malleable iron is only a half of that of gray iron, perhaps because of lower silicon.

It may be mentioned that the test bars from these heats were subjected to the regular malleablizing annealing. Their properties, however, were very much the same as those of the regular cupola malleable, *i. e.* tensile strength, 45,000 to 55,000 lb. per sq. in.; yield point, 33,000 to 37,000 lb. per sq. in.; elongation, 7 to 9 per cent; torsion, 90 to 100 per cent revolution; and Brinell hardness 138 to 145.

---

[1] Crane Company, Chicago, Ill.
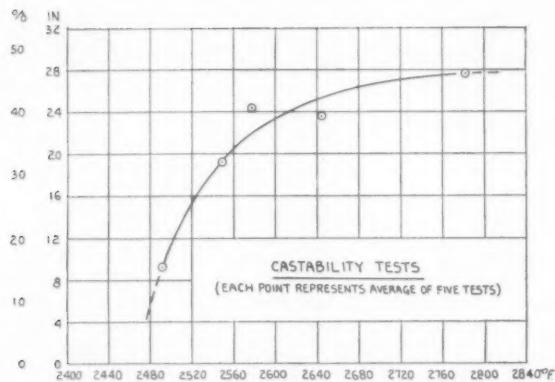
FIG. 5 — CASTABILITY DATA, AS AFFECTED BY THE POURING TEMPERATURE.

The only conclusion that could be drawn from these experiments is that superheating does not contribute anything to the properties of the malleablized metals, as compared to those of the standard cupola malleable, and the only justification for superheating of the melt is in improved castability.

PROF. ASH: The composition of the malleable iron poured from the air furnace was:

Si.	Mn.	S.	C.
%	%	%	%
1.12	0.50	0.13	2.50

Analyses were not made of the remelted electric furnace heats. The data from all runs did not justify a curved relationship, hence straight lines were drawn through all data. This same condition existed in many gray iron tests and also aluminum alloys and bronzes. All the observations made by Saeger and Krynitsky never indicated justification for drawing a curved relationship between pouring temperature and spiral length.

Regarding Fig. 5, I would like to point out that the points indicated at 2780, 2645 and 2550° F. indicate a straight line relationship. Data from the 2490° F. tests should not be included because this sharp break in the curve indicates that the metal was poured too near the liquidus temperature (about 2350° F. for this composition). Before entering the spiral, the metal was already in the freezing range (primary crystals had already formed).

This same phenomenon was observed by Joseph[2] in his paper on fluidity of malleable irons. He obtained a straight line relationship until he poured at too low a temperature, allowing the metal to partially solidify as it was passing through the basin and gate.

[2] Joseph, C. F., "Measuring and Controlling Pouring Temperatures and Fluidity," TRANS. A.F.A., vol. 44, p. 103 (1936).

C. E. SIMS:[3] This method that is used by Prof. Ash is undoubtedly a method which will give comparative results as is indicated by the straight line curves he obtained. However, it seemed to me that there would be a drop in temperature during the filling of the cup due to contact with the core sand, so that while the data undoubtedly are comparable and show the trends, it would be rather difficult to correlate the length of spiral directly with the temperature as measured. It is important, I believe, to know as nearly as possible the correct temperature of the metal as it enters the spiral.

PROF. ASH: In any practical test of this nature for measuring fluidity, there will be a continued drop in temperature as the metal leaves the ladle. This drop in temperature will vary with different modifications; but regardless of any design for introducing the metal, there will always be a relationship between the temperature of the metal as it leaves the ladle and the spiral length obtained. The temperature drop is relatively unimportant, within reasonable limits. But, the real important factor is reproducibility of results through elimination of as many variables as possible.

C. H. LORIG:[4] I was interested in a remark that Prof. Ash made to the effect that when the foundryman found that his fluidity test rods were running short, he corrected the metal. I wonder what corrections were made to improve the fluidity while the heat was in the furnace.

PROF. ASH: It would be proper for Mr. Schumacher to reply to this question.

GEO. SCHUMACHER:[5] I cannot speak particularly from an investigational standpoint. My experience has been more or less in duplexing iron for about 19 months, and some of the effects that we have had upon the flowability of our iron, that is, pouring fluidity molds at various times during the day. We are running about 100 tons of metal a day, and at various times the pouring crew reports back that the iron acts sluggish. I check the analysis and it is found that it is comparable to what has been the analysis for the last two or three hours, varying, we will say, from 1.05 to 1.12, in silicon, and from 2.45 to 2.55 in carbon, with the manganese adjusted to compensate for the sulphur (sulphur about 0.12 per cent).

When that condition has occurred, the first urge is to vary the composition, to put in a little coke and get the iron a little higher in carbon, or put in a little silicon. However, by so doing you are playing with fire in that you are going to vary your physical properties.

My deduction has been, in several instances, that the cause of this was due to the raw materials that were entering into the cupola and

[3] Battelle Memorial Institute, Columbus, O.
[4] Battelle Memorial Institute, Columbus, O.
[5] Albion Malleable Iron Co., Albion, Mich.

subsequently into the air furnace, with a possible carry-over of a greater amount of oxides. Perhaps our steel, which was used in the mix at that particular time, contained a lot of Fe_2O_3 after it came through into the air furnace.

For that reason, we have been practicing slag control. Slag control is practiced in the air furnace, and we do this with a silica sand and limestone. After we have covered this bath to a certain extent, we have observed a noticeable change in the flowing power of our metal. Such slag manipulation maintained the flowability of the metal at a point where it was originally before the pouring gang discovered that the flowability was reduced.

I thoroughly believe in a good live slag for helping to reduce oxides in the metal. I think, partially, the flowability of our metal is reduced due to the oxides included in the metal. These oxides are hard to overcome owing to their introduction into the original charge as it enters the cupola. I have noted that at the close of the day or the beginning of the next day, when we pulled off the last slag in the air furnace from the previous day's melt, that that slag totaled as high as 19 per cent FeO. After we get the last slag out of the furnace, during the day the FeO will decrease to between 5 and 6 per cent. We have checked the FeO content over an 8 or 9-hour run and have found our cupola slags were running between 3.25 and 4 per cent.

I believe the flowability and the running power on like compositions, with like temperatures of white cast iron can be decidedly improved by proper slag control.

MR. SIMS: I would like to say a few words about the temperature measurements. The English paper that Professor Ash referred to, was by Dr. R. J. Sargent of Hadfield's, Ltd. I talked to Dr. Sargent within the last two months and found he has some more recent information. A good many of those earlier tests in which he obtained these very discordant results, fluidities running all over the map without any apparent correlation with fluidity, were made with optical temperature readings. Since then, he has repeated a great deal of that work, taking temperatures with thermocouples, and since the results now fall into nice smooth curves, he has eliminated a great many of these differences. In other words, what it amounts to is that the emissivities of these metals varied greatly and threw him off on the temperature readings. He will soon publish these data. He found that the various methods of melting changed the emissivity, and also that metal in the furnace sometimes varied after it got into the ladle. The more accurate readings obtained with the thermocouples straightened out a lot of the apparent discrepancies.

F. HOLTBY:[6] I am glad that point was brought up on this paper just presented by Professor Ash. I think the emissivity value has been

---

[6] University of Minnesota, Minneapolis, Minn.

overlooked. We have found, at the University of Minnesota, that ladle additions will change the emissivity value radically and these changes in emissivity will give us errors in readings of as high as 375° F., as checked against the thermocouple.

On an air furnace, metal is tapped from the bottom of the bath and the emissivity corrections are entirely different with that type of metal. A metal tapped from the indirect-arc electric furnace is tapped from the top of the bath and the slag comes off and any additions changes the emissivity corrections and, unless they are calculated, the temperature readings are incorrect.

PROF. ASH: There are no facts available to dispute the point raised by Mr. Holtby. This possible error can only be checked by using a thermocouple for similar check runs. However, it appears doubtful that in the case of the electric furnace melt, a deoxidizer addition should give an emissivity factor in the opposite direction of that obtained when a deoxidizer is added to the air furnace metal. This latter point is difficult to refute.

MEMBER: I would just like to bring out, in connection with the pouring basin, that the higher the temperature, the greater would be that drop in temperature in the pouring basin that would tend to make a curve instead of a straight line on those graphs. This would tend to bear out Mr. Ziegler's statement that they are curves rather than straight lines.

PROF. ASH: It is true that the higher the pouring temperature, the greater will be the loss of temperature before the metal enters the spiral. This is true for all pouring conditions, the original design as well as any modification. However, this temperature differential would really cause the curve to be convex upward, while the curve Mr. Ziegler has drawn is convex downward, the exact opposite of what should be obtained due to greater temperature loss at high pouring temperatures.

CHAIRMAN HALLIWELL: In view of the difficulty that Prof. Ash first had in checking his results, I would like to know whether he took into account some of the work that Draegeholt did in finding out that humidity apparently had some effect on the malleabilization of cast irons and whether that might not have some effect on his fluidity.

PROF. ASH: No study was made on the effect of humidity.

Effect of Superheating on Castability and Physical Properties of Cast Irons of Different Carbon Contents

By N. A. Ziegler* and H. W. Northrup**, Chicago, Ill.

Abstract

Commercial gray iron was remelted in a high frequency induction furnace and cast into spiral "castability" molds and standard test bar molds as follows: (1) superheated to 3000°F. (1650°C.) and cast from 3000°F. (1650°C.), (2) superheated to 3000°F. (1650°C.) and cast from 2800°F. (1540°C.), (3) superheated to 3000°F. (1650°C.) and cast from 2600°F. (1430°C.), (4) superheated to 2800°F. (1540°C.) and cast from 2800°F. (1540°C.) and (5) superheated to 2600°F. (1430°C.) and cast from 2600°F. (1430°C.). The same set of melts was repeated with cast irons in which carbon content was reduced to (1) 3.00, (2) 2.50, and (3) 2.25 per cent.

From the samples thus assembled, the effect of superheating and of the pouring temperature on castability and physical properties of these cast irons has been determined.

Castability is increased by increasing carbon content, pouring temperature and temperature of superheat. Curves determining these relationships are presented. Transverse bend strength, Brinell hardness, tensile strength and proportional limit are increased by decreasing carbon. Higher pouring temperature increases these properties which is particularly true about cast irons of lower carbon contents. Quantitative relationships are presented in graphic form. Metallographic examination reveals that superheating tends to eliminate free ferrite, refine and localize graphitic flake, and break up dendritic formations, thus illustrating the corresponding improvement of physical properties. This is particularly true for cast irons of lower carbon contents.

INTRODUCTION

1. The present investigation was undertaken with the object of obtaining some information on fundamental properties of gray iron. Some results have been assembled, which, although still incomplete, are of interest to us in the sense of establishing a broad foundation upon which further experimentation and investigation may be conducted. Hence, this paper is written in the spirit of a progress report, describing the first chapter of our experimentation on gray iron. No definite recommendations are attempted to be presented, but if a foundryman will find in it something that may give him a constructive idea, the purpose of this paper will be accomplished.

2. Standard gray iron of the general composition shown in Table 1 was used as a raw material in this work:

Table 1

GENERAL COMPOSITION OF RAW MATERIAL USED IN RESEARCH

Silicon, Percent	2.20
Manganese, Percent	0.55
Sulphur, Percent	0.114
Phosphorus, Percent	0.39
Total Carbon, Percent...	3.24

Using a 200 lb. high frequency induction furnace as melting equipment, five melts were performed as follows:† (1) Charge superheated to 3000°F. (1650°C.) and cast at 3000°F. (1650°C.), (2) Charge superheated to 3000°F. (1650°C.) and cast at 2800°F. (1540°C.), (3) Charge superheated to 3000°F. (1650°C.) and cast at 2600°F. (1430°C.), (4) Charge superheated to 2800°F. (1540°C.), and cast at 2800°F. (1540°C.), (5) Charge superheated to 2600°F. (1430°C.) and cast at 2600°F. (1430°C.).

3. The same set of melts was repeated on cast irons in which carbon content was reduced to (1) 3.00, (2) 2.50, and (3) 2.25 per cent, thus making altogether 20 experimental melts. During the experimental procedure, the melting pot of the furnace was left open to the atmosphere, and no special precautions were taken to prevent reaction of the charge with air. Carbon contents were regulated by adding to the charges predetermined amounts of ingot iron, and silicon was maintained constant by additions of ferro-silicon. The rest of the elements, although varied somewhat from heat to heat, remained of the same order of magnitude, as can be seen in Table 2.

---

† Description of the induction melting equipment is given in the Addendum.

4. Each heat was poured in five alternately arranged spiral "castability" molds, as developed by the Bureau of Standards and described by Saeger and Krynitsky,†* and five standard test bar molds, all made of green sand. As may be noted, in each group of five melts the first three were superheated to 3000°F. (1650°C.). The first one was poured from this temperature, the second one, before pouring, was cooled in the crucible to 2800°F. (1540°C.), and the third to 2600°F. (1430°C.) The fourth and fifth heats were poured from 2800°F. (1540°C.) and 2600°F. (1430°C.), correspondingly, without superheating. In each case, temperature during melting and superheating periods was controlled with an optical pyrometer. While pouring each mold, temperature of the metal was likewise measured. It should be appreciated that due to cooling of the metal during pouring the recorded temperatures were somewhat lower than desired. Nevertheless, by repeating some of the melts, it has been ascertained that the temperature measurements were sufficiently accurate.

5. Each heat thus produced five spiral "castability" castings and five test bars, all of which were subjected to testing. The chemical analysis of each heat was likewise determined. Data thus assembled is summarized in Table 2.

6. It was felt that recording of the results obtained on each individual sample would make this presentation unduly long. Hence, only average results for each heat are presented, thus making each figure of Table 2 (with the exception of chemical data) an average of five tests. It may be noted that, although physical properties of individual samples of each heat varied somewhat, they all were of the same order of magnitude, thus making average figures of Table 2 sufficiently representative.

7. The "castability" data and physical properties of these castings will now be discussed separately.

CASTABILITY DATA

8. The castability molds were made from the pattern, as recommended by Saeger and Krynitsky, except that the gate connecting the pouring hole with the horn gate was, for reasons of convenience, lengthened from 1-11/16 to 3-13/16 in. The spiral is 60 in. long and is marked with 30 buttons at 2 in. distance. De-

---

† * Saeger, C. M. Jr. and Krynitsky, A. I. *"A Practical Method for Studying the Running Quality of a Metal Cast in Foundry Molds."* Trans. A. F. A., Vol. 39, 1931, pp. 513-540

Table 2

SUMMARY OF THE EXPERIMENTAL DATA ON GRAY IRON

(Each figure, with the exception of Chemical Analysis, is an average of five tests)

Coating Type	Superheat Temp. °F.	Superheat Temp. °C.	Avg. Pouring Temp. °F.	Avg. Pouring Temp. °C.	Spiral Length In.	Spiral Length %	% Si	% Mn	% S	% P	% T.C.	Transverse Strength Lb. per Sq. In.	Deflection In.	Bhn	Cast Bar Tensile Strength Lb. per Sq. In.	Machined Bar Tensile Strength Lb. per Sq. In.	Proportional Limit Lb. per Sq. In.	Elongation Elastic + Plastic	% Elongation Plastic	Modulus of Elasticity Lb. per Sq. In. x 10⁶
GROUP I — CARBON 3.25 PER CENT																				
A* Spiral	3000	1650	2870	1580	60	100	2.24	0.56	0.115	0.39	3.22									
A Test Bar	3000	1650	2870	1580			2.24	0.56	0.115	0.39	3.22	3970	0.14	214	35,400	30,410	9,080	0.67	0.42	12.2
B Spiral	3000	1650	2710	1490	54	90	2.24	0.56	0.115	0.39	3.25									
B Test Bar	3000	1650	2710	1490			2.24	0.56	0.115	0.39	3.25	3920	0.15	203	34,250	31,740	9,620	0.75	0.49	12.2
C Spiral	3000	1650	2560	1400	42	70	2.24	0.57	0.115	0.39	3.20									
C Test Bar	3000	1650	2560	1400			2.24	0.57	0.115	0.30	3.20	3850	0.14	201	35,000	32,960	10,230	0.61	0.39	15.0
D Spiral	2800	1540	2640	1450	40	82	2.24	0.56	0.115	0.39	3.25									
D Test Bar	2800	1540	2640	1450			2.24	0.56	0.115	0.30	3.25	3840	0.15	201	34,500	29,480	8,960	0.68	0.47	14.0
E Spiral	2600	1430	2480	1360	32	53	2.05	0.50	0.110	0.38	3.30									
E Test Bar	2600	1430	2480	1360			2.05	0.50	0.110	0.38	3.30	3775	0.15	197	31,550	25,580	7,880	0.87	0.66	12.2
GROUP II — CARBON 3.00 PER CENT																				
A* Spiral	3000	1650	2840	1650	55	92	2.10	0.50	0.108	0.35	2.96									
A Test Bar	3000	1650	2840	1650			2.10	0.50	0.108	0.35	2.96	4751	0.14	222	42,050	42,400	10,000	0.62	0.35	15.7
B Spiral	3000	1650	2720	1490	51	85	2.10	0.50	0.105	0.37	2.95									
B Test Bar	3000	1650	2720	1490			2.10	0.50	0.105	0.37	2.95	4686	0.17	217	43,050	38,250	10,000	0.70	0.44	14.7
C Spiral	3000	1650	2480	1360	30	50	2.25	0.54	0.083	0.36	2.88									
C Test Bar	3000	1650	2480	1360			2.25	0.54	0.083	0.36	2.88	4240	0.15	217	39,280	39,050	9,500	0.59	0.40	16.7
D Spiral	2800	1540	2620	1440	44	70	2.31	0.53	0.084	0.38	2.88									
D Test Bar	2800	1540	2620	1440			2.31	0.53	0.084	0.38	2.88	4652	0.17	216	43,000	41,090	11,930	0.79	0.54	16.4
E Spiral	2600	1430	2510	1380	25	42	2.15	0.47	0.088	0.39	3.00									
E Test Bar	2600	1430	2510	1380			2.15	0.47	0.088	0.39	3.00	4090	0.14	210	39,130	32,580	9,600	0.70	0.49	15.5

Table 2 — *Continued*

GROUP III — CARBON 2.50 PER CENT

A* Spiral	3000	1650	2860	1570	47	78	2.29	0.46	0.068	0.36	2.46	5380	0.18	249	53,000	52,260	21,230	0.90	0.60	17.4
A Test Bar	3000	1650	2860	1570			2.29	0.46	0.068	0.36	2.46									
B Spiral	3000	1650	2770	1520	43	72	2.29	0.45	0.070	0.38	2.53	5180	0.16	231	52,950	47,580	20,300	0.60	0.83	17.6
B Test Bar	3000	1650	2770	1520			2.29	0.45	0.070	0.38	2.53									
C Spiral	3000	1650	2590	1420	21	35	2.25	0.46	0.068	0.36	2.47	4910	0.15	230	48,560	49,180	16,630	0.78	0.53	19.6
C Test Bar	3000	1650	2590	1420			2.25	0.46	0.068	0.36	2.51									
D Spiral	2800	1540	2690	1480	34	57	2.29	0.46	0.068	0.34	2.51	5320	0.17	225	51,750	47,950	20,750	0.63	0.35	17.1
D Test Bar	2800	1540	2690	1480			2.29	0.46	0.068	0.34	2.58									
E Spiral	2600	1430	2570	1410	17	28	2.25	0.45	0.072	0.36	2.58	4120	0.12	220	38,960	37,080	14,700	0.51	0.31	18.5
E Test Bar	2600	1430	2570	1410			2.25	0.45	0.072	0.36	2.58									

GROUP IV — CARBON 2.25 PER CENT

A* Spiral	3000	1650	2850	1570	42	70	2.38	0.41	0.068	0.33	2.23	5310	0.14	255	55,680	35,190	23,000	0.26	0.06	17.6
A Test Bar	3000	1650	2850	1570			2.38	0.41	0.068	0.33	2.23									
B Spiral	3000	1650	2720	1490	38	55	2.29	0.41	0.044	0.32	2.18	5400	0.15	241	54,140	49,520	23,630	0.52	0.26	19.1
B Test Bar	3000	1650	2720	1490			2.29	0.41	0.044	0.32	2.18									
C Spiral	3000	1650	2590	1420	15	25	2.29	0.41	0.044	0.32	2.18	5000	0.14	249	47,860	48,930	22,600	0.56	0.32	20.2
C Test Bar	3000	1650	2590	1420			2.29	0.41	0.044	0.32	2.18									
D Spiral	2800	1540	2680	1470	30	50	2.27	0.36	0.058	0.28	2.14	5380	0.14	248	49,000	51,180	22,300	0.57	0.31	19.7
D Test Bar	2800	1540	2680	1470			2.27	0.38	0.058	0.28	2.24									
E Spiral	2600	1430	2580	1420	10	17	2.29	0.40	0.054	0.30	2.24	4435	0.15	236	46,280	41,610	15,700	0.53	0.31	18.9
E Test Bar	2600	1430	2580	1420			2.29	0.40	0.054	0.30	2.24									

*NOTE: (A) Superheated to 3000°F., poured at 3000°F. (B) Superheated to 3000°F., poured at 2800°F. (C) Superheated to 3000°F., poured at 2600°F. (D) Superheated to 2800°F., poured at 2800°F. (E) Superheated to 2600°F., poured at 2600°F.

pending on the nature of the alloy subjected to castability test and its pouring temperature, the spiral of the mold may be filled anywhere from 100 per cent to zero. By counting the number of the buttons on the resultant casting, the castability of the given alloy may be expressed, either in terms of the length of the spiral or in per cent. Fig. 1 represents three typical castings of this series, indicating high, intermediate and low castability. No special precautions were taken in pouring castability molds, except that it was ascertained that the feeding reservoir and its "appendix" were completely filled. In the majority of cases, each heat resulted in five spirals of somewhat decreasing length, caused by cooling of the metal during pouring. The average pouring temperatures and spiral lengths for each heat are presented in Table 2.
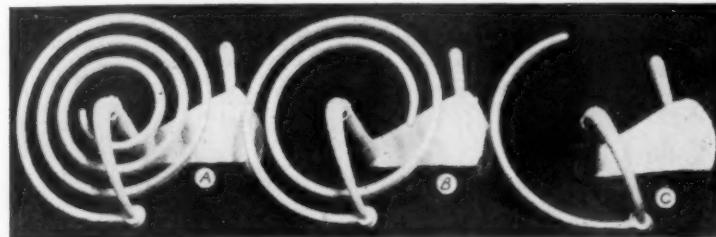

Fig. 1—Representative "Castability" Test Castings. (A) High Castability. (B) Intermediate Castability. (C) Low Castability.

9. In Fig. 2-A castability data for each carbon content is plotted as a function of the pouring temperature. As a result we have four curves, each representing castabilities of four cast irons, of different carbon contents, and each tending to become asymptotic at some elevated temperature. Curve No. 1, castability of cast iron containing 3.25 per cent carbon, is at 100 per cent at about 2840 to 2880°F. (1560 to 1580°C.) and tends to come to zero at about 2400°F. (1320°C.).

10. Curves No. 2, 3 and 4 represent castabilities of cast irons of decreasing carbon contents (i. e. of about 3.00, 2.50 and 2.25 per cent carbon, respectively). Each one of these is at its maximum in the vicinity of 2840 to 2880°F. (1560 to 1580°C.). This maximum, however, decreases with decreasing carbon to about 90, 75 and 70 per cent castability, respectively. The temperature at which each one of these curves comes to zero, on the other hand, increases to about 2430, 2520 and 2560°F. (1330, 1380 and 1400°C.) respectively. This is natural to expect, because decrease in carbon
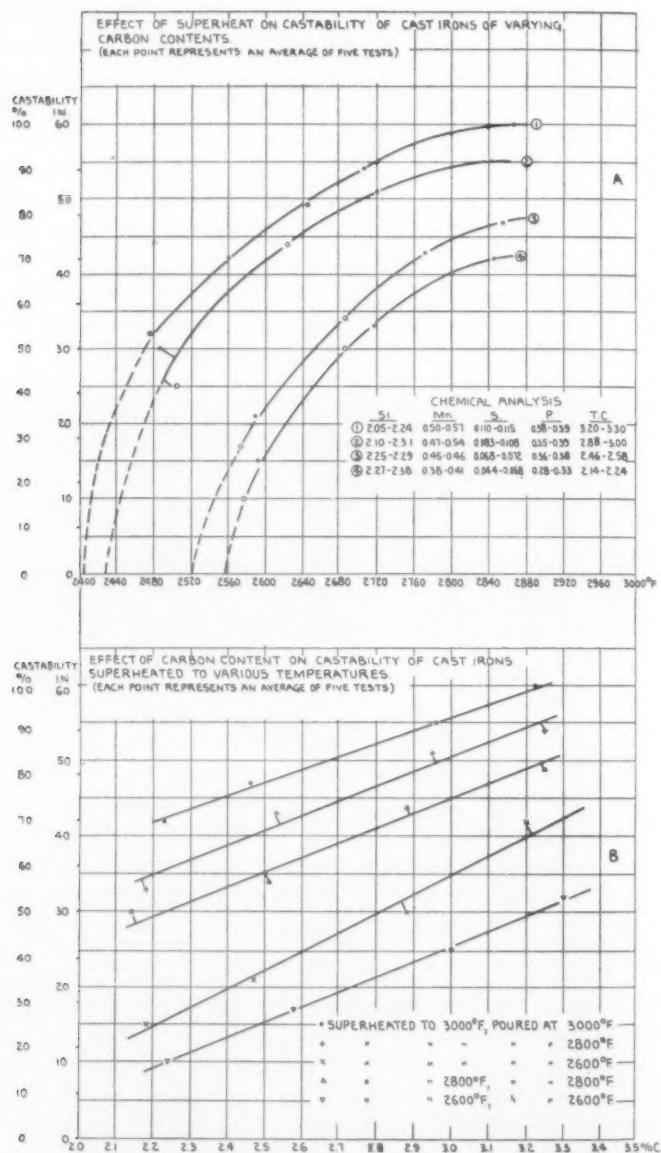
FIG. 2—CURVES SHOWING CASTABILITY PLOTTED AGAINST POURING TEMPERATURE AND AGAINST CARBON CONTENT.
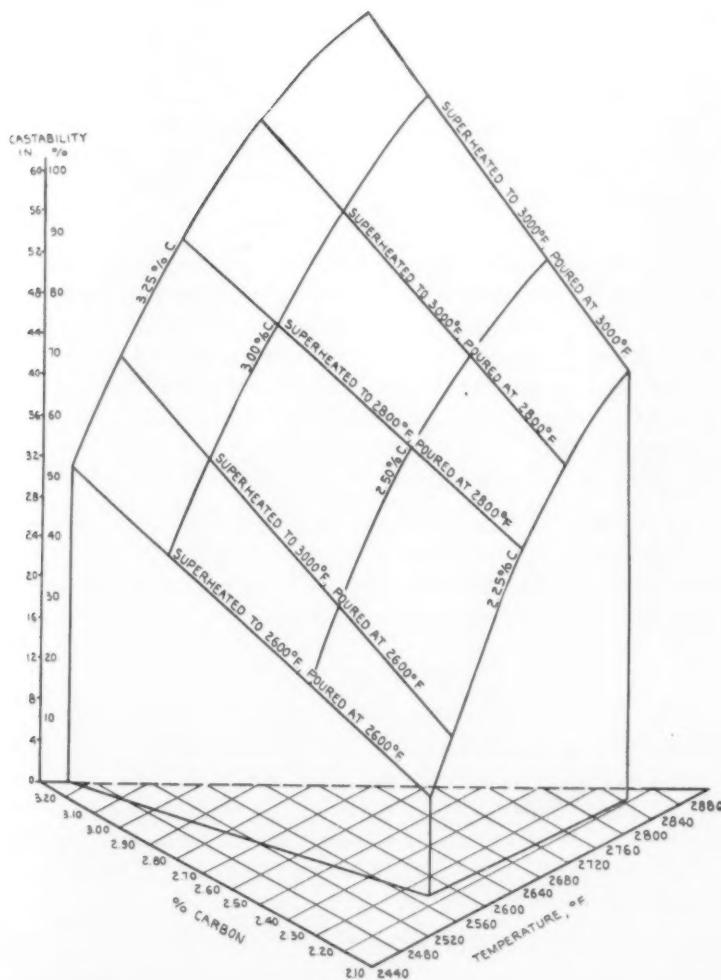
FIG. 3—EFFECT OF SUPERHEAT AND CARBON CONTENT ON CASTABILITY OF CAST IRON.

raises the melting point of the metal and makes it more sluggish, thus resulting in the lowering of castability.††

11. In Fig. 2-B, the same data is plotted on castability vs. carbon content coordinates. As a result we have five straight lines, each representing the effect of carbon content on castability, under given pouring conditions. It appears that the influence of carbon content on castability is a straight line relationship and that castability is affected not only by the pouring temperature, but also by the degree of superheat: melts superheated to 3000°F. (1650°C.) and poured at 2800 and 2600°F. (1540 and 1430°C.) indicate higher castabilities than melts poured from the same temperatures but without previous superheating.

12. To summarize these observations, a conclusion may be drawn that castability of cast iron is affected by (1) the carbon content,*** (2) pouring temperature, and (3) conditions of pouring or degree of superheat. Time of pouring, on the other hand, does not seem to have much influence; it has been measured and recorded for each individual mold with a stop watch and varied anywhere between 3 and 10 sec. Curves of Fig. 2, however, do not indicate this time variation.

13. Using the data presented in Fig. 2, Fig. 3 has been constructed, where an attempt has been made to represent, by a three-dimensional model or a space diagram, the effect of carbon content and of the pouring temperature on castability.

PHYSICAL DATA

14. Each test bar casting was subjected to transverse bend, Brinell hardness and tensile test. In addition, a standard (0.505 in. round) tensile test piece was machined from each transverse test bar and was likewise subjected to tensile testing. Average figures for each heat, resulting from these experiments, are summarized in Table 2. Each one of the physical properties will now be discussed separately.

Transverse Bend Strength (Cast Bars)

15. The transverse bend strength data has been plotted as a

†† In each curve of this and following "A" figures, dots represent data of the melts superheated to 3000°F. (1650°C) and cast at 3000, 2800 and 2600°F. (1650, 1540, and 1430°C.), while open circles represent data of the melts poured from 2800 and 2600°F. (1540 and 1430°C.), without superheating.

*** Perhaps it would be more correct to say "chemical composition," because other elements, like silicon, manganese, sulphur and phosphorus, always present in cast irons, undoubtedly will likewise affect the castability, but they are not covered by the present investigation and for this reason not considered.
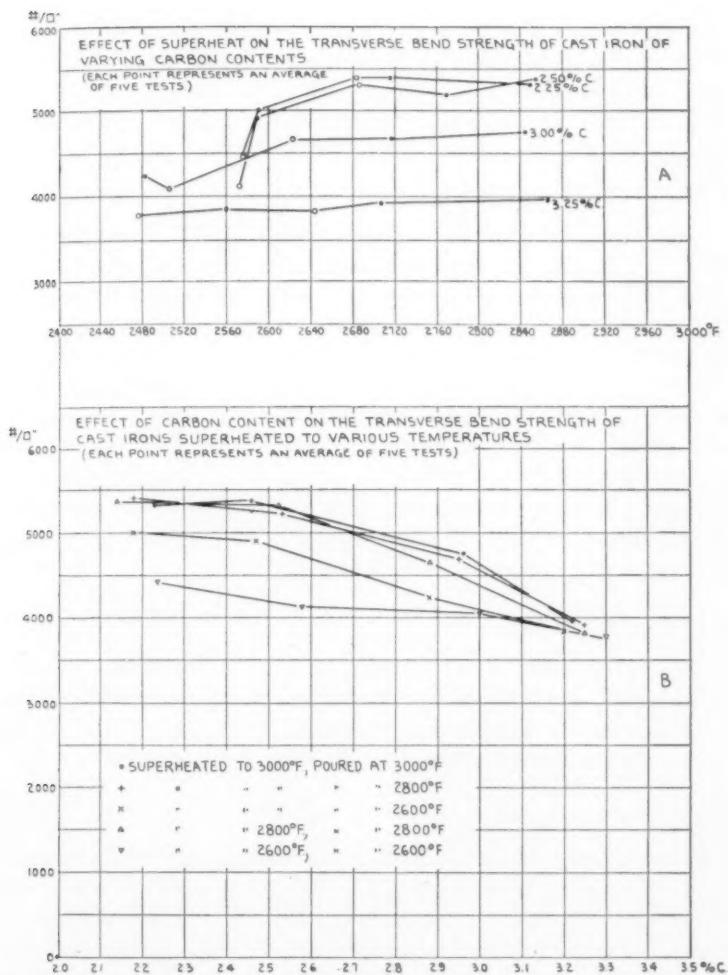
FIG. 4—CURVES SHOWING EFFECT OF SUPERHEAT AND EFFECT OF CARBON CONTENT ON TRANSVERSE BEND STRENGTH.

function of pouring temperature (Fig. 4-A) for cast irons of different carbon contents, and as a function of carbon content (Fig. 4-B) for cast irons poured under identical conditions.

16. From Fig. 4-A it may be judged that superheating contributes practically nothing to the cast iron of 3.25 per cent carbon. However, the transverse bend strength of 3.00 per cent carbon iron is improved by superheating to 2800°F. (1540°C.) from about 4200 to 4700 lb. per sq. in. or by 12 per cent, and of 2.50 and 2.25 per cent carbon irons from about 4300 to 5400 lb. per sq. in., or by 26 per cent.

17. Fig. 4-B indicates that in case of melts poured from 2600°F. (1430°C.) (without superheating) reduction of carbon from 3.25 to 2.25 per cent raises the transverse bend strength from 3750 to 4400 lb. per sq. in., or about 15 per cent. In case of melts superheated to 3000°F. (1650°C.) and poured from 2600°F. (1430°C.), about the same carbon reduction results in an increase of the transverse bend strength from 3750 to 5000 lb. per sq. in., or 33 per cent; while heats superheated to 3000°F. (1650°C.) and poured from 3000°F. (1650°C.) and 2800°F. (1540°C.), as well as those poured from 2800°F. (1540°C.) (without superheating) are improved by the same reduction in carbon content from about 3800 to 5400 lb. per sq. in. or 42 per cent.

Deflection (Cast Bars)

18. Deflection of the transverse bend bars varied anywhere between 0.11 and 0.19 in. No correlation, however, could be found between it and carbon content or pouring conditions. This probably was due to insufficient sensitivity of the testing machine.

Brinell Hardness

19. Brinell hardness, as may be seen from Fig. 5-A, seems to be affected, only to a small degree, by pouring temperature; increase of the latter from 2480 to 2860°F. (1360 to 1570°C.) causes increase in Brinell hardness of about 5 to 11 per cent. It appears that this increase is higher for cast irons of lower carbon.

20. Fig. 5-B shows that decrease of carbon from 3.25 to 2.25 per cent results in an increase of Brinell hardness from 200 to 240 or about 20 per cent. It may be noted that the hardness of heats poured from 3000°F. (1650°C.) in each case is about
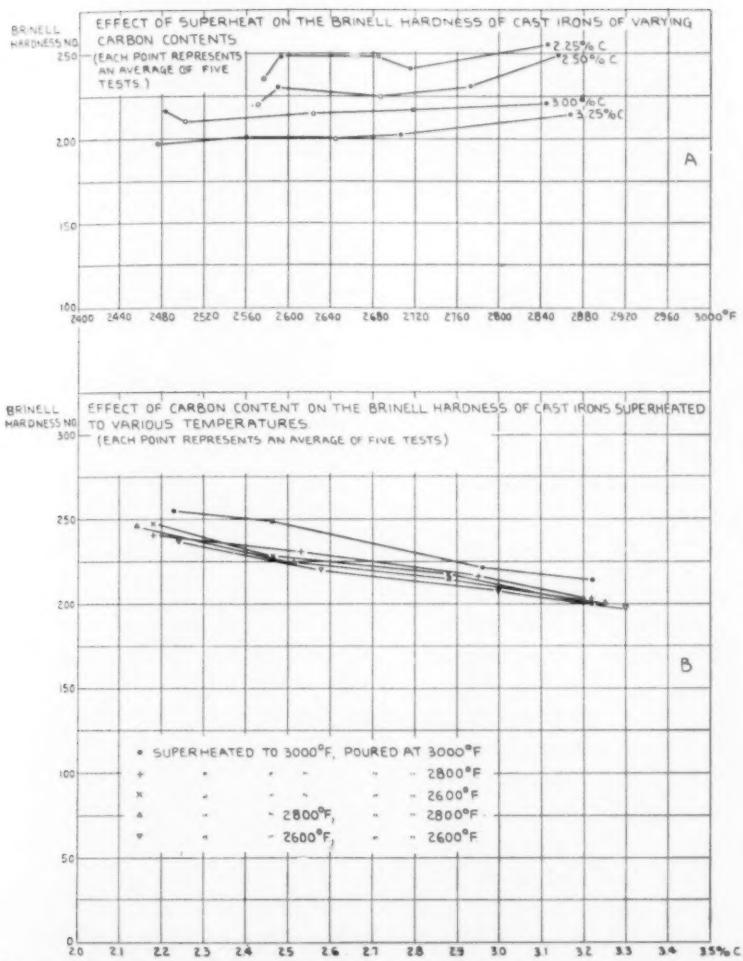
Fig. 5—Curves showing Brinell hardness plotted against carbon content and against pouring temperatures.
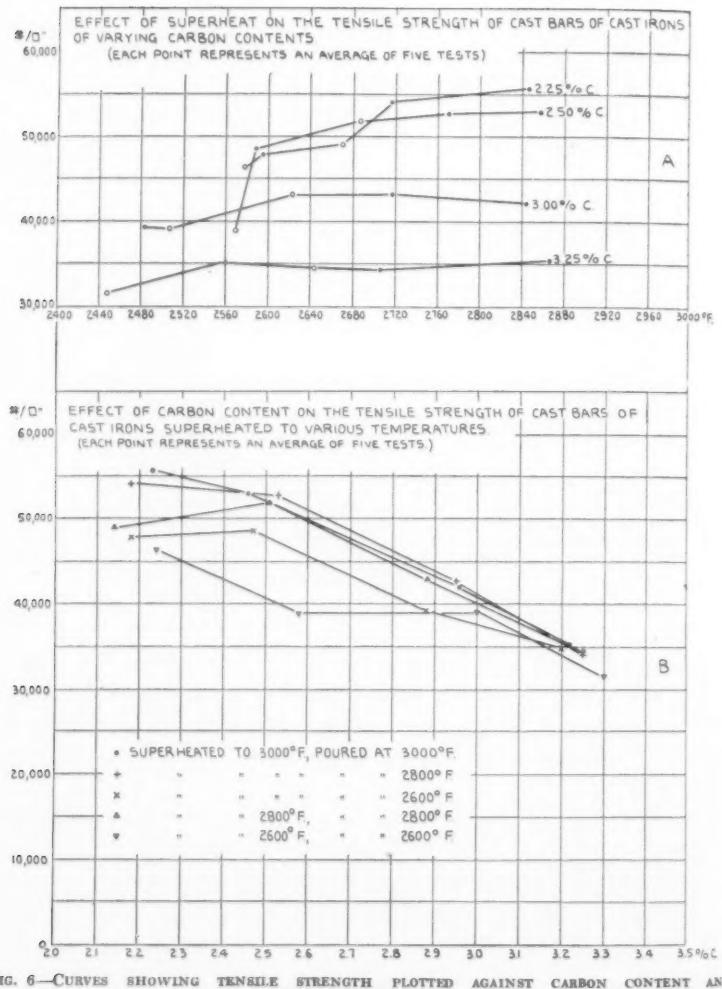
FIG. 6—CURVES SHOWING TENSILE STRENGTH PLOTTED AGAINST CARBON CONTENT AND POURING TEMPERATURE.

5 to 10 per cent higher than that of heats poured at lower temperatures.

Tensile Strength (Cast Bars)

21. Fig. 6-A indicates a strong effect of high temperature pouring on the tensile strength of cast irons, particularly those of low carbon contents. By raising pouring temperature from 2440 to 2880°F. (1340 to 1580°C.), tensile strength of 3.25 per cent carbon iron is increased from 32,000 to 35,000 lb. per sq. in. or 9 per cent; of 3.00 carbon iron from 39,000 to 43,000 lb. per sq. in. or 10 per cent; of 2.5 per cent carbon iron from 39,000 to 53,000 lb. per sq. in., or 36 per cent; and of 2.25 per cent carbon iron from 46,000 to 56,000 lb. per sq. in. or 22 per cent.

22. Fig. 6-B shows the increase in tensile strength from about 35,000 to 55,000 lb. per sq. in. or 57 per cent, caused by decrease of carbon from 3.25 to 2.25 per cent. It may be noted that the three curves representing heats poured from 2800°F. (1540°C.) or higher, are above the two curves representing heats poured from 2600°F. (1430°C.), thus demonstrating once more that superheating of any one of the tried compositions to above temperature results in a stronger metal.

Tensile Strength and Proportional Limit (Machined Bars)

23. With one or two exceptions, the tensile strength of machined bars is somewhat lower than that of cast bars (Table 2), which is a well known phenomenon, explained by the removal by machining, of the chilled skin. When plotted as a function of pouring temperature (Fig. 7-A) and of carbon content (Fig. 7-B), the resultant curves are quite similar to those of Figs. 6-A and 6-B, i.e. those representing the tensile strength of cast bars, and thus do not require any additional comments. It should be pointed out that the tensile strength of the machined bars of 2.25 per cent carbon iron, superheated to 3000°F. (1650°C.) and poured from this temperature, came out abnormally low, which is not true about the cast bars of the same heat. (Figs. 6-A and 6-B).

24A. This anomaly was subjected to a careful investigation. Several melts, duplicating conditions of the one under consideration, have been performed. Curiously enough, the results of any other melt could be reproduced without any difficulty, but this particular one always gave very erratic results: sometimes test bars thus prepared (cast as well as machined) would pull at over
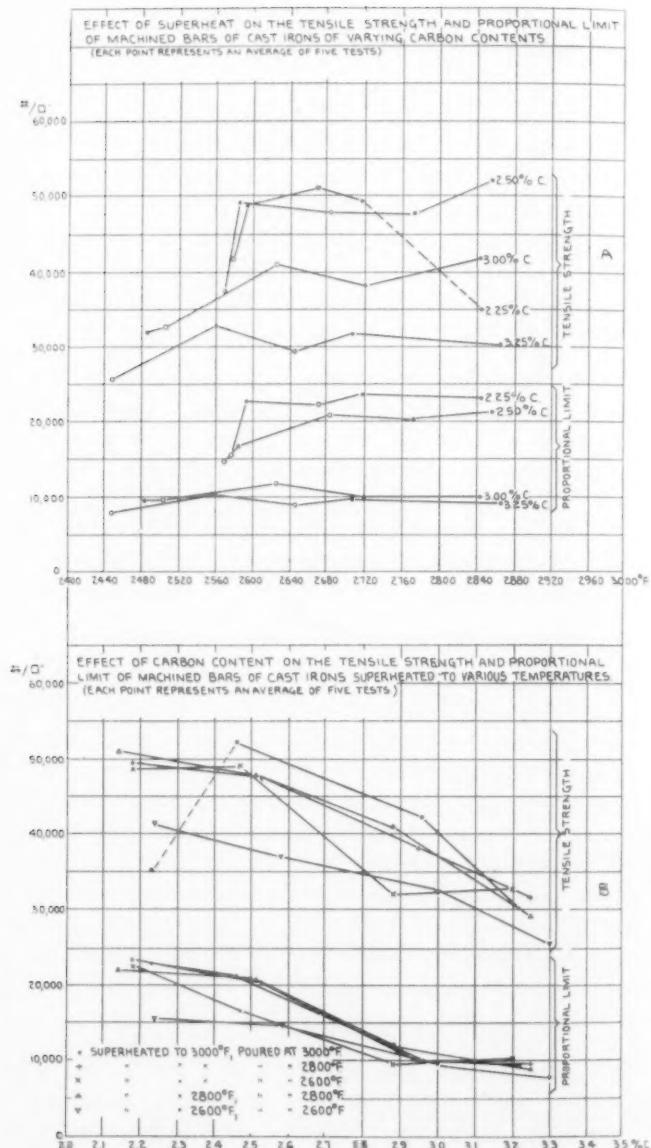
FIG. 7—CURVES SHOWING THE EFFECT OF POURING TEMPERATURE AND EFFECT OF CARBON CONTENT ON TENSILE STRENGTH AND PROPORTIONAL LIMIT.

50,000 lb. per sq. in., and sometimes they would break at less than 30,000 lb. per sq. in. On careful examination of these bars, it was established that those which had high tensile strength were quite sound, while those that were weak had fine internal cracks. Our opinion is that this low carbon, highly superheated iron is quite susceptible to shrinkage. In the particular heat, the results of which are presented in this paper, the "cast tensile test bar" portions of the castings were sound and thus gave high results. The "transverse test bar" portions from which machined tensile test bars were made, on the other hand, had shrinkage cavities, and thus were weak. In duplicate heats we had the experience of sometimes having the same results, sometimes having the entire casting sound, thus giving high tensile strength (cast as well as machined bars), and sometimes having the entire casting porous, thus giving low tensile strength. Our opinion is that when this highly superheated low carbon iron is cast so that it results in a sound metal—it always pulls at about 50,000 lb. per sq. in. or even higher, but to reproduce such results consistently, it may be necessary to change the design of the test bar pattern. It may be that the observations of previous investigators, that superheating iron beyond a certain degree, results in a weaker metal, may be due to the same cause.

24. Machined bars were tested in a hydraulic tensile testing machine with an automatically recorded stress-strain diagram, which enabled us to determine the proportional limit of all the samples. Fig. 7-A shows that the effect of superheating on proportional limit of 3.25 and 3.00 per cent carbon irons is negligibly small (if any). In case of 2.50 and 2.25 per cent carbon irons, however, raising the pouring temperature from 2570 to 2850°F. (1410 to 1570°C.) results in an increase of proportional limit from about 15,000 to 22,000 lb. per sq. in., or 45 per cent.

25. Decrease of carbon from 3.25 to 2.25 per cent (Fig. 7-B) results in an increase of proportional limit from about 9,000 to 23,000 lb. per sq. in. or 150 per cent. Again it may be noted that the proportional limits of heats poured from higher temperatures, in the majority of cases, are higher than those of the heats poured at lower temperatures.

Elongation (Machined Bars)

26. From the automatically recorded stress-strain diagrams, elongation (plastic as well as elastic + plastic) was determined
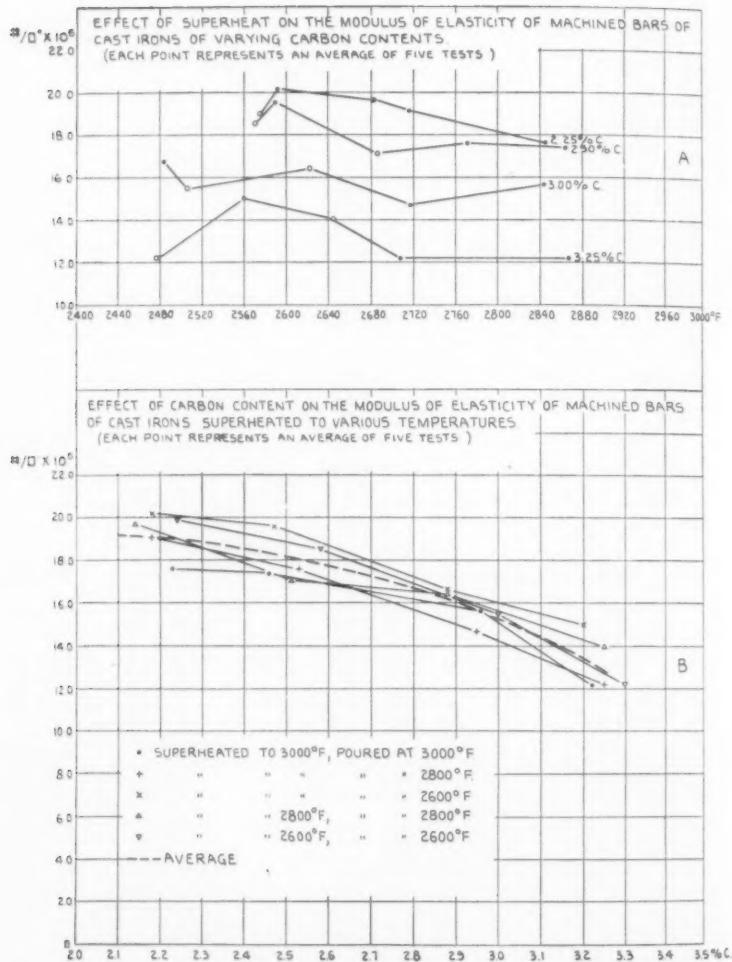
FIG. 8—CURVES SHOWING MODULUS OF ELASTICITY PLOTTED AGAINST POURING TEMPERATURE AND AGAINST CARBON CONTENT.
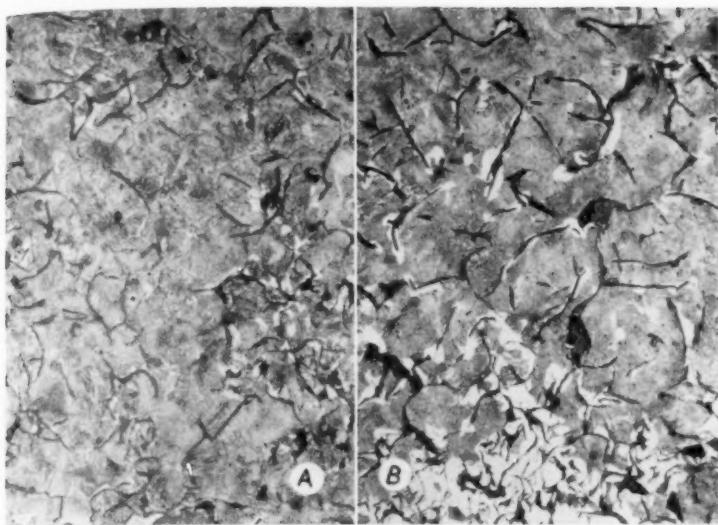
FIG. 9—Photomicrographs at 150X. Etched with nital.

(A) SAMPLE NO. AC

Chemical Analysis:

Si—2.24 per cent, Mn—0.56 per cent, S—0.115 per cent, P—0.39 per cent, T. C.—3.25 per cent.

Physical Properties:

Brinell Hardness—207.
Tensile Strength—39,900 lb. per sq. in.
Proportional Limit—10,500 lb. per sq. in.
Elongation {Plastic—0.56 per cent.
{Plastic + Elastic—0.82 per cent
Modulus of Elasticity—15.3x10⁶ lb. per sq. in.

Pouring:

Superheated to 3000°F. (1650°C.)
Poured at 2800°F. (1540°C.)
Measured Pouring Temperature—2650°F. (1450°C.)

(B) SAMPLE NO. AM

Chemical Analysis:

Si—2.24 per cent, Mn—0.56 per cent, S—0.115 per cent, P—0.39 per cent, T. C.—3.25 per cent.

Physical Properties:

Brinell Hardness—197.
Tensile Strength—25,200 lb. per sq. in.
Proportional Limit—10,500 lb. per sq. in.
Elongation {Plastic—0.24 per cent.
{Plastic + Elastic—0.44 per cent
Modulus of Elasticity—12.5x10⁶ lb. per sq. in.

Pouring:

Poured from 2800°F. (1540°C.) without superheating.
Measured Pouring Temperature—2630°F. (1440°C.)

(see Table 2). Its maximum variation was between 1.13 per cent total and 0.84 per cent plastic maximum (individual sample from the 2.50 per cent carbon iron heat, poured from 3000°F. (1650°C.)), and 0.27 per cent total and 0.09 per cent plastic minimum (individual sample from the 2.25 per cent carbon iron heat, poured from 2600°F. (1430°C.)). Between these limits elongation did not seem to have any well defined relation either to carbon content or to pouring temperature. It appears that other factors, such as structural characteristics, had a far greater influence. Thus, no attempt is being made to present elongation results graphically.

Modulus of Elasticity (Machined Bars)

27. From the tensile strength and elastic elongation data of the machined bars an attempt has been made to compute the modulus of elasticity of the samples. These results have been plotted as a function of pouring temperatures (Fig. 8-A) and of carbon content (Fig. 8-B). It is admitted that the inconsistency of the elongation data makes these results tentative. Nevertheless, in view of the fact that they present a few points of interest, they, for the sake of record, are included in this presentation.

28. Fig. 8-A indicates that there is no apparent correlation between the modulus of elasticity and the pouring temperature. From Fig. 8-B, however, it seems that carbon content of the metal does influence its value; considering only average values for each carbon content, modulus of elasticity increases with decreasing carbon from 13.0×10^6 lb. per sq. in. (for 3.25 per cent carbon) to 19.0×10^6 lb. per sq. in. (for 2.25 per cent carbon). The intermediate values form a smooth curve, slightly convex upwards. This is in good agreement with the values presented in the Cast Metals Handbook.†††

MICROEXAMINATION

29. A considerable number of tested bars has been subjected to metallographic examination. No quantitative relationship between physical properties on one hand and structural characteristics, size and distribution of graphite flake on the other, could be established. Nevertheless some interesting qualitative observations have been recorded. From each one of four groups of cast irons of different carbon contents, machined bars of the highest and of the lowest tensile strength have been selected, irrespective of their casting conditions, and photographed (in polished and etched condition) at 150 diameters magnification. Figs. 9, 10, 11 and 12 represent these samples for 3.25, 3.00, 2.50 and 2.25 per cent carbon irons respectively. In each case the "A" photographs represent samples of the highest, and "B" photographs of the lowest tensile strength. In the subscript under each photograph, the chemical analysis, physical properties and pouring conditions of the given sample are recorded.

30. Invariably, in each case, the sample of higher tensile strength (A photographs) has more pearlite and less free ferrite,

† †† Cast Metals Handbook, A.F.A., 1935 Edition, p. 89.
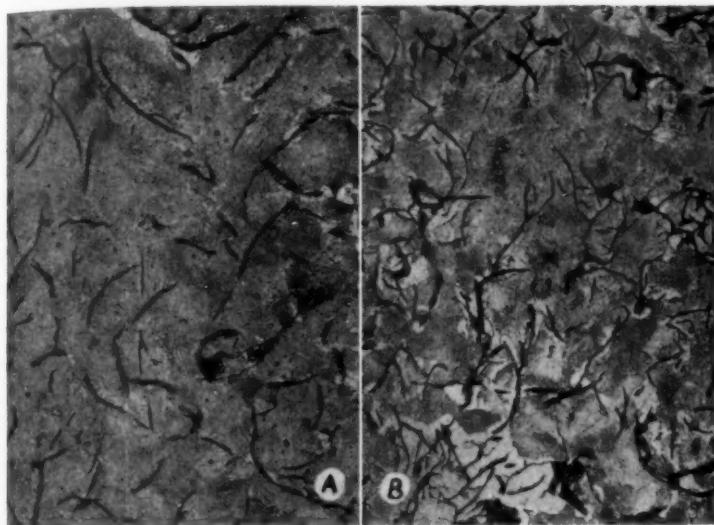
FIG. 10—PHOTOMICROGRAPHS AT 150X. ETCHED WITH NITAL.

(A) SAMPLE NO. BL

Chemical Analysis:

Si—2.31 per cent, Mn—0.53 per cent, S—0.084 per cent, P—0.38 per cent, T. C.—2.88 per cent.

Physical Properties:

Brinell Hardness—217.
Tensile Strength—42,350 lb. per sq. in.
Proportional Limit—13,500 lb. per sq. in.
Elongation {Plastic—0.66 per cent. {Plastic + Elastic—0.94 per cent
Modulus of Elasticity—15.1x10⁶ lb. per sq. in.

Pouring:

Poured from 2800°F. (1540°C.) without superheating.
Measured Pouring Temperature—2600°F. (1480°C.)

(B) SAMPLE NO. BQ

Chemical Analysis:

Si—2.15 per cent, Mn—0.47 per cent, S—0.088 per cent, P—0.39 per cent, T. C.—3.00 per cent.

Physical Properties:

Brinell Hardness—207.
Tensile Strength—31,100 lb. per sq. in.
Proportional Limit—11,500 lb. per sq. in.
Elongation {Plastic—0.44 per cent. {Plastic + Elastic—0.66 per cent
Modulus of Elasticity—14.1x10⁶ lb. per sq. in.

Pouring:

Poured from 2600°F. (1430°C.) without superheating.
Measured Pouring Temperature—2430°F. (1330°C.)

than the sample of lower tensile strength (B photographs). Moreover, in the case of the former, graphite flakes are more "localized" and separated from each other than in the case of the latter. In the latter case graphite flakes tend to form more or less continuous paths, sometimes associated with formation of dendritic pattern, as shown quite clearly in Figs. 11-B and 12-B. It is obvious that such continuity of graphite results in lowering of physical properties of the metal. It is interesting to note that, in each case, ductility, as expressed by per cent elongation is lower for "B" samples, i.e. for those in which graphite is arranged in a more continuous pattern. Proportional limit and Brinell hardness are

either equal in corresponding "A" and "B" samples or lower in case of "B"'s. It should be understood that "A" and "B" in each case tend to represent structural characteristics of the two extreme cases, regarding the physical characteristics, and that between them all the rest of the samples for each group are arranged, as indicated in the aforerepresented curves, associated with inevitable scattering, resulting from the experimental error. However, in each case the "A" samples were superheated to higher temperatures than "B", which leads us to the obvious conclusion that superheating of the melt is beneficial in the sense of reducing the amount of free ferrite, refining graphitic flake, breaking up
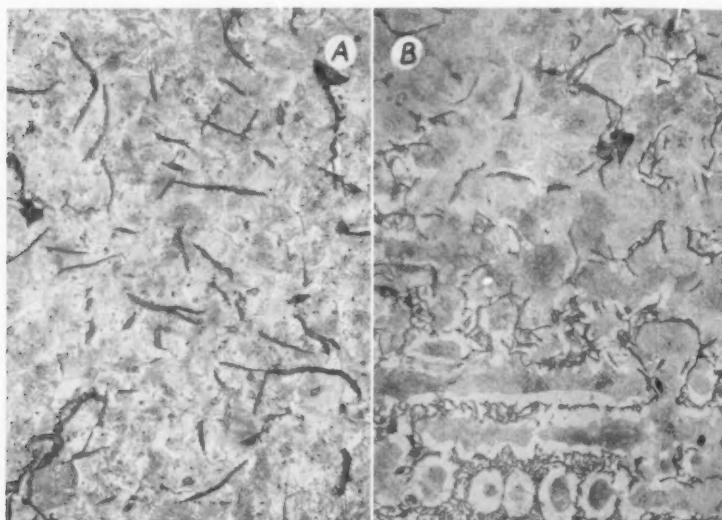
FIG. 11—PHOTOMICROGRAPHS AT 150X. ETCHED WITH NITAL.

(A) SAMPLE NO. BS

Chemical Analysis:

Si—2.29 per cent, Mn—0.46 per cent, S—0.068 per cent, P—0.86 per cent, T. C.—2.46 per cent.

Physical Properties:

Brinell Hardness—229.
Tensile Strength—55,000 lb. per sq. in.
Proportional Limit—20,000 lb. per sq. in.
Elongation {Plastic—0.84 per cent.
{Plastic+Elastic—1.13 per cent
Modulus of Elasticity—18.9x10⁶ lb. per sq. in.

Pouring:

Superheated to 3000°F. (1650°C.)
Poured at 3000°F. (1650°C.)
Measured Pouring Temperature—2870°F. (1580°C.)

(B) SAMPLE NO. CP

Chemical Analysis:

Si—2.25 per cent, Mn—0.45 per cent, S—0.072 per cent, P—0.36 per cent, T. C.—2.58 per cent.

Physical Properties:

Brinell Hardness—229.
Tensile Strength—36,000 lb. per sq. in.
Proportional Limit—16,000 lb. per sq. in.
Elongation {Plastic—0.29 per cent.
{Plastic+Elastic—0.50 per cent.
Modulus of Elasticity—17.1x10⁶ lb. per sq. in.

Pouring:

Poured from 2600°F. (1430°C.) without superheating.
Measured Pouring Temperature—2560°F. (1400°C.)
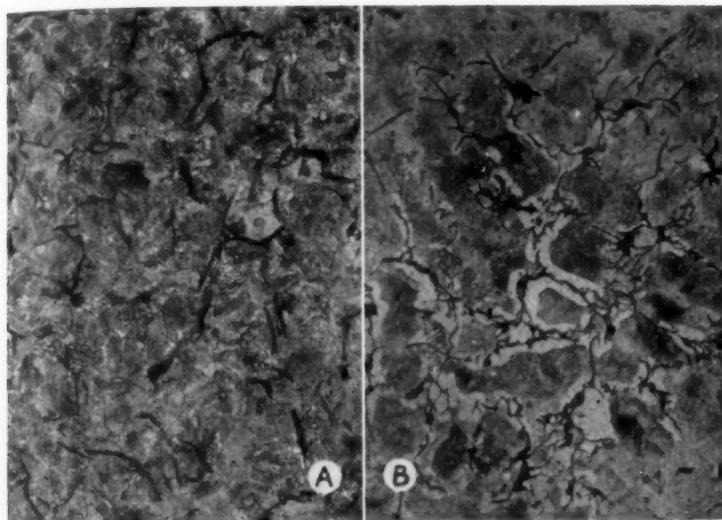
FIG. 12—PHOTOMICROGRAPHS AT 150X. ETCHED WITH NITAL.

(A) SAMPLE NO. CY

Chemical Analysis:

Si—2.29 per cent, Mn—0.41 per cent, S—0.044 per cent, P—0.32 per cent, T. C.—2.18 per cent.

Physical Properties:

Brinell Hardness—241.
Tensile Strength—57,300 lb. per sq. in.
Proportional Limit—26,500 lb. per sq. in.
Elongation {Plastic—0.61 per cent.
{Plastic+Elastic—0.93 per cent
Modulus of Elasticity—17.9x10⁶ lb. per sq. in.

Pouring:

Superheated to 3000°F. (1650°C.)
Poured at 2800°F. (1540°C.)
Measured Pouring Temperature—2720°F. (1490°C.)

(B) SAMPLE NO. DO

Chemical Analysis:

Si—2.29 per cent, Mn—0.40 per cent, S—0.054 per cent, P—0.30 per cent, T. C.—2.24 per cent.

Physical Properties:

Brinell Hardness—241.
Tensile Strength—34,500 lb. per sq. in.
Proportional Limit—17,000 lb. per sq. in.
Elongation {Plastic—0.09 per cent.
{Plastic+Elastic—0.27 per cent.
Modulus of Elasticity—19.2x10⁶ lb. per sq. in.

Pouring:

Poured from 2600°F. (1430°C.) without superheating.
Measured Pouring Temperature—2560°F. (1400°C.)

its continuity and eliminating dendritic formations, thus improving physical properties. All these effects are more pronounced in lower carbon irons.

SUMMARY

(1) Effects of superheating and of carbon content on "castability" and on physical properties of cast irons containing 3.25, 3.00, 2.50 and 2.25 per cent carbon, have been investigated.

(2) Castability is determined by carbon content of cast iron, pouring temperature and degree of superheat.

(3) Curves representing castability of cast irons of different carbon contents, as affected by pouring temperature, came to zero at some temperatures, which vary from about 2400°F. (1320°C.) for cast iron containing 3.25 per cent carbon, to 2560°F. (1400°C.) for cast iron containing 2.25 per cent carbon. These curves become asymptotic with respect to the temperature axis at about 2900°F. (1600°C.). The maximum castability at that temperature varies from about 100 per cent for cast iron containing 3.25 per cent carbon to 43 per cent for cast iron containing 2.25 per cent carbon.

(4) Effect of carbon content on castability presents a straight line relationship. With carbon increasing from 2.25 to 3.25 per cent, castability is increased by about 30-40 per cent, depending on the pouring temperature.

(5) Superheating cast iron to a high temperature and pouring it at some lower temperature, results in a higher castability than pouring from the same temperature without superheating.

(6) Effects of superheating and of carbon content on physical properties of cast iron have been investigated.
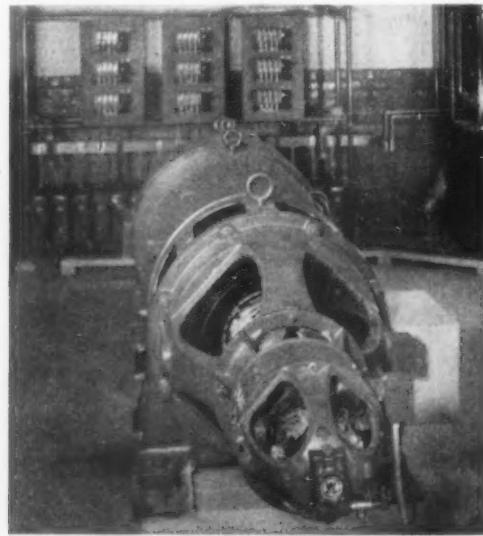

FIG. 13—HIGH FREQUENCY MOTOR-GENERATOR SET.

(7) Decreasing carbon increases the transverse bend strength, depending on pouring temperature, 15 to 42 per cent.

Superheating to about 2800°F. (1540°C.) improves the transverse bend strength. This improvement is more pronounced in case of cast irons of lower carbon contents, and, depending on the latter, may be as much as 26 per cent.

(8)   Brinell hardness of cast iron is increased by about 20 per cent by decreasing carbon content. Effect of superheating on Brinell hardness, on the other hand, is quite small.

(9)   Tensile strength of cast and machined bars of cast iron increases with decreasing carbon as much as 50 per cent, depending on the pouring temperature. Tensile strength of lower carbon cast irons is increased by superheating to about 2800°F. (1540°C.) as much as over 40 per cent. In general, with few exceptions, cast bars are stronger than machined ones.

(10)   Proportional limit of machined bars increases with decreasing carbon by as much as 150 per cent. Proportional limit of lower carbon cast irons is increased by superheating as much as 45 per cent.

(11)   An attempt has been made to compute modulus of elasticity of these samples. It appears that it is not influenced by superheating, but with carbon increasing from 2.25 to 3.25 per cent, decreases from 19.0×10^6 to 13.0×10^6 lb. per sq. in. These figures, however, are offered as tentative.

(12)   It appears that 2800°F. (1540°C.) is the most advantageous pouring temperature; it results in nearly maximum castability and maximum physical properties for all four cast irons investigated. Although higher temperatures may improve these properties still further, this improvement is too small to justify additional superheating.

(13)   Metallographic examination reveals that for each carbon content superheating tends to decrease the amount of free ferrite, refine graphite flake and break its continuity, thus improving physical properties of the metal. This effect is particularly apparent in cast irons of lower carbon content.

***

Addendum I — Melting Equipment

The melting equipment used at Crane Co.'s Research Laboratories consists of a 110 k.w. high frequency motor generator, (Fig. 13) and two 200-lb. furnaces (Fig. 14).

As a driving mechanism, a 200 h.p. synchronous motor is used. The generator, which together with the exciters is mounted on the
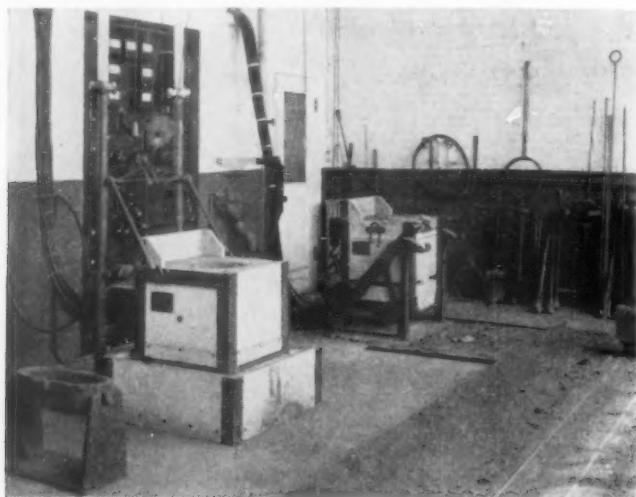
FIG. 14—GENERAL VIEW OF THE EXPERIMENTAL HIGH FREQUENCY MELTING EQUIPMENT.

same shaft and base plate with the motor, is arranged to produce 110 k.w., 960 cycles current. Some of the capacitors are connected permanently, while others are connected at will by means of contactors. In this way the operator can maintain unity power factor at all times. To make sure that the furnace can draw full power at all stages of the melt and under all conditions of the charge, current and power factor are watched on the meters, mounted on the control panel board, and are corrected by means of the coil "tap" switches. These are simple interlocked switches, which can be changed rapidly when desired.

A high frequency induction furnace is really a water cooled transformer, whose primary is the furnace coil and whose secondary is the charge. The primary is a helical coil of copper tubing, insulated between turns, through which water is being circulated for cooling the copper. When high frequency current is applied to the terminals of the helix, all the space inside of the coil is subjected to a rapidly alternating electro-magnetic field. Any electrical conductor inside of the coil (in this case the furnace charge) has currents induced in it, which cause rapid and efficient heating. In a properly designed high frequency furnace, usually the only

limitation in obtaining high temperatures, is the deterioration of refractories.

FIG. 15—THE "LIFT COIL" HIGH FREQUENCY FURNACE IN WHICH THE EXPERIMENTAL CAST IRON MELTS WERE MADE.

Of the two 200 lb. furnaces with which Crane Co.'s experimental melting unit is equipped, one is of a tilting type and is used for making steels. After a steel melt is completed, the entire furnace is tilted by an overhead electric hoist, the melt is poured into a ladle and thence cast into molds. The other furnace is of the "lift coil" type and is used for making cast irons, brasses, bronzes, monel metal, etc. In it all melts, discussed in the present paper, have been made. It is so constructed that, upon completion of the melt, its entire coil is lifted, which leaves the crucible filled with molten metal free to be carried to the molds (Fig. 15). No ladle or ladle heaters are required with the lift coil furnace. Standard crucibles are used and mixtures can be changed at will, using new crucibles, if desired, for each mixture.

Only one furnace can be operated at a time, and for doing so a "throw over" panel is used. On this panel are two sets of switches. By throwing them one way the tilting furnace is energized; by throwing them the other way the lift coil furnace is operated.

The main advantages of high frequency furnaces are extreme flexibility and ease with which they can be operated, which insure
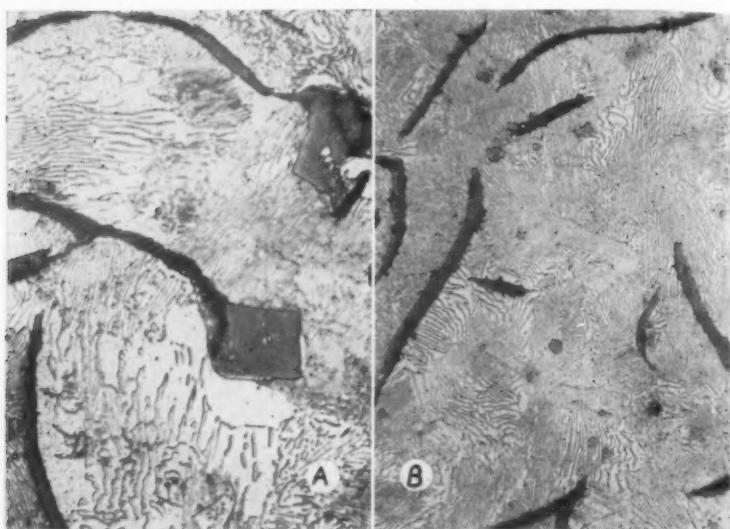
FIG. 16—PHOTOMICROGRAPHS ETCHED WITH NITAL. (A) SAMPLE No. AM. (SAME AS IN FIG. 9-B) 1000X. (B) SAMPLE No. BS. (SAME AS IN FIG. 11-A) 500X.

excellent reproducibility of results. Since heat is developed in the charge itself and no heaters of any type are used, purity of the melts and freedom from contaminations are at their best. If necessary, the entire furnace may be enclosed in an airtight shell, from which all air may be pumped out. Melts thus may be made either in vacuum or in any controlled atmosphere.

Addendum II

All samples subjected to metallographic investigation have also been examined at high power magnification. This revealed only a small amount of further information which would throw additional light on the subject under discussion. Nevertheless, two of the samples, AM (represented in Fig. 9-B) and BS (represented in Fig. 11-A) were photographed and are presented in Fig. 16-A and 16-B. Their interest is primarily in the illustration of the fact that non-metallic inclusions act as nuclei of graphitization, which is particularly well demonstrated in Fig. 17-A. Here two graphite flakes, both of which apparently grow from inclusions, are shown.

DISCUSSION

Presiding: W. H. SPENCER, Sealed Power Corp., Muskegon, Michigan.

WAYNE L. COCKRELL[1] *(Written Discussion):* The paper is notably lacking in any comment on the literature regarding this subject. This is particularly noteworthy as some of the conclusions are directly opposed to accepted notions of the effect of the effects of superheat.

The effect of carbon content upon the castability at any given temperature is generally recognized and requires no further showing at this time and with this conclusion there can be no other objection. The difference in castability shown for the same pouring temperature with differences in superheating are not very great, 30-25, 21-17, 15-10, neglecting slight differences in observed pouring temperatures. These slight differences of observed temperature may account for the difference in fluidity. The absence of any data on the reproducibility obtained on the several tests from which these averages were calculated is unfortunate in view of the small difference. Do the several tests of which these figures are the average check with each other closer than say 5?

The findings in regard to the microstructure are far from agreement with previous observers, and it is strange that the authors make no comment upon this point. Looking at Fig. 9 "A" and "B" without reference to the data under these micrographs, one who has previously examined superheated iron would pick "B" as the superheated one. The difference is more striking in the case of Fig. 11 "A" and "B," where the superheated structure would be even more positively identified as the one which the authors state was not superheated. The micrographs and their accompanying description almost lead one to suspect that in the preparation of the specimens for microexamination the superheated and unsuperheated specimens became reversed.

N. A. ZIEGLER AND H. W. NORTHRUP: Replying to Professor Cockrell's discussion, we have not included any survey of previously published information, to avoid unnecessary repetition and making our paper unduly long. For the same reason, our numerical data are presented in a condensed form. However, to the best of our knowledge, a quantitative investigation of the effect of carbon content, pouring tem-

---

[1]Assistant Professor, Michigan State College, East Lansing, Mich.

perature and degree of superheat on the resultant castability of gray iron has not been presented before.

As we have pointed out in presenting the paper, we can duplicate by repeated runs the castability results within about 2 per cent. Results of the repeated runs are not included in the paper, for the sake of space economy. The only exception in reproductibility of the results are the physical properties of the low carbon (about 2.5 per cent carbon), highly superheated composition. As pointed out in the revised paper, it appears to be highly susceptible to shrinkage. For this reason, sound bars made of such metal break at 50,000 lb. per sq. in., while those that have internal cracks (sometimes of microscopic size) may fail at less than 30,000 lb. per sq. in.

In our opinion, our photomicrographs substantiate, rather than contradict previously existing information. Pearlite is stronger than ferrite, hence irons with uniform pearlitic matrix should be stronger than those composed of a mixture of pearlite and ferrite. Moreover, superheating tends to produce this uniform structure, as well as to break up the dendritic formations. These two facts, we believe, are illustrated by our photographs.

In conclusion we would like to emphasize that our paper is based on the results of laboratory tests and it is up to the foundrymen to use them to their advantage.

C. H. LORIG[2] *(Written Discussion):* The results reported by the authors on the effect of superheating gray cast iron of varying composition is of extreme interest and gives further evidence of the unique influence of metal temperature on the structure and mechanical properties of irons. They also lead one to wonder whether irons in the liquid state as regards their constitution, are not affected by superheat.

These authors seem to be the first to call attention to the increased castability of cast iron resulting from superheating the metal. Obviously, for the castability to increase, some change must have taken place in the liquid iron such as, perhaps, an alteration in the nature and content of its inclusions and its gases, or in the constitution, *i.e.* the compound composition of the melt itself.

Di Giulio and White determined[3] the gas content of superheated gray iron by the vacuum fusion method and showed a definite decrease in oxygen content with increased temperature. Thus with increased degrees of superheat the content of the oxygen bearing inclusions both in solution and in suspension in the melt, apparently, is diminished. That in itself may account for a change in viscosity of the metal and hence in its castability. Whether it would account for the total change or even for an increase in castability is still unknown. Other solid or liquid inclusions besides those containing oxygen are in iron; however, it is unlikely their amount would be changed materially on superheating or that they would be responsible for the change in castability.

The nitrogen and hydrogen contents of the cast iron, according to the work of Di Giulio and White, bore no relationship to the temperature of superheat. In this case, equilibrium may not have been reached between the gases and the molten iron. Raising or lowering the gas content of iron by control of the metal temperature may affect its castability; nevertheless, the consistent improvement which the authors found in their superheating experiments could hardly be accounted for by a change in gas concentration in the melt alone.

An extremely interesting hypothesis to account for the variations in the qualities of iron was given by Professor McCaffery[4]. This hypothesis suggests that differences in the compound composition of iron in the liquid state "may account for variations in properties of heats of the same chemical composition that are explained usually in various other ways." Quoting again from this article, it is stated that "pig iron or cast iron will always be found on chemical analysis to contain iron and manganese and carbon, silicon, sulphur and phosphorus. With the exception of part of the iron and carbon which may exist in the pig iron in the elemental form as ferrite and graphite, all the commoner metallic constituents of the pig iron form compounds with the non-metallic constituents which may be present and binary compounds like carbide of iron, carbide of manganese, silicide of iron, silicide of manganese, sulphite of iron, sulphite of manganese, phosphide of iron and phosphide of manganese as well as possible compounds more complex than binaries, may be present in the iron."

That compounds may exist in liquid iron is a plausible concept, and is gaining support as we continue to learn more about the liquid state of matter. Dissociation of these compounds with increase of superheat or changes in the relative proportions of the compounds due to their differences in stability with temperature are possibilities which conceivably could account for the change in castability that the authors reported.

The authors reported the use of standard crucibles in the preparation of the melts. Presumably they were of clay-graphite. If that is so, it seems possible that the observations made as regards the structural characteristics, size and distribution of the graphite flakes in the irons as affected by the degree of superheat can be partly explained by the inoculating effect of graphite taken up by the melt from the crucible. Very small quantities of graphite added to melts late in the heat are known to have a profound influence on the character of the graphite in cast iron. Graphite additions are particularly effective in reducing the tendency for the graphite in the iron to be dendritic. Graphite can be taken up by cast iron from clay-graphite crucibles at high temperatures.

For the above reasons, it seems possible that the obvious conclusion reached by the authors on page 641 to the effect "That superheating of the melt is beneficial in the sense of reducing the amount of free ferrite, refining graphitic flake, breaking up its continuity and eliminating den-

[4]TRANSACTIONS, American Foundrymen's Association, vol. 35, pp. 427-437 (1927).

dritic formations, thus improving physical properties" is to some extent conditioned by the method of preparing the melts.

Our experience with high frequency electric furnace melting of 100 to 300 lb. heats of cast iron in a magnesia or a silica crucible have also shown that the amount of free ferrite is reduced and that the graphite flakes are refined by increased superheat above a certain range of temperature. However, we have observed no tendency for superheating to eliminate the dendritic formations of graphite, in fact of a number of series of heats of iron examined there was no case where the amount of dendritic graphite did not increase with increased temperature up to 3150° F. These irons were made without late or ladle additions. On the other hand, similar series of heats made with late or ladle additions of ferrosilicon, calcium silicide, graphite, etc., showed that these additions to cast irons partially or wholly eliminated the dendritic formation of graphite.

The fact that the authors observed a reversion of the graphite form in the cast irons from the dendritic to the flake type on increasing the temperature of superheat indicated a possible innoculating effect from graphite taken up by the melts from the crucible at the high superheating temperatures.

Photomicrograph Fig. 17 is interesting, but the mere fact that the two manganese sulphide inclusions and the two graphite flakes shown intersect is not proof that the graphite flakes both grew from these inclusions. The mechanism of freezing of cast iron would not postulate such a conclusion and for that reason it is extremely doubtful that the photograph is an illustration of the fact that non-metallic inclusions act as nuclei for graphitization. It is more likely a case of random intersection.

Transverse and deflection data indicate that a 1.2-in. diameter bar tested on 12-in. centers was employed. The article fails to mention the length of the span. The results should not be confused with those obtained on bars tested with an 18-in. span.

F. HOLTBY[5]: In connection with Fig. 2 of this paper, have the authors by any chance melted any metal and kept the superheat temperature below 2900° F. and poured at some lower temperature? In all cases this paper showed superheat temperatures above 3,000° F. and pouring temperatures below, 2800 to 2600° F., and that at the lower temperatures he superheated and poured at the same temperature. The reason I ask this is that, after about 100 heats of test iron that we are running at the University of Minnesota at the present time, we found that manganese sulphide has some peculiar property affecting flowability. Manganese sulphide has a melting point of 2960° F. and it seems as if the changing of this constituent from a solid to a liquid would have something to do with the flowability, and if we stay below this melting point of 2960° F., we again change our flowability ratio compared to the superheating temperature and the pouring temperature.

MR. ZIEGLER: Mr. Lorig's remarks are much appreciated. It is quite likely that the chemical composition, and particularly gas content of molten iron may be modified by temperature thus affecting its fluidity. But it should not be overlooked that all liquids (unless they have an allotropic transformation like sulphur) become more fluid with the increasing temperature. The viscosity of water, for example, according to the International Critical Tables, at 0°C. is 17.93 millipoises, while at 100°C. only 2.83.

The problem of gases in cast iron has been investigated so little that we feel any discussions on it at present are purely speculative. We propose therefore to postpone them until a later date when more experimental evidence will be available.

The remark about our melts picking up carbon from the crucible is very interesting and requires further consideration. The crucibles used by us were made of clay-graphite, which well justifies the hypothesis of slight carbon absorption.

Mechanism of graphitic flake formation is really beyond the scope of this paper, and the photograph, Fig. 16, was included merely to illustrate at a high magnification a typical structure of one of our irons. However, it should not by any means be considered as "two manganese sulphide inclusions and two graphite flakes" intersecting. It illustrates something that has been observed on numerous occasions. Careful polishing technique and high magnification studies very frequently reveal association of inclusions and graphite flakes. In fact, we feel justified in stating that, if carefully examined, most of graphite flakes have inclusions attached to them. We are not prepared to advance any theory as to whether inclusions act as nuclei of graphitization, or whether a graphite flake progresses in its formation until it comes in contact with an inclusion and then stops, perhaps in a way similarly to a crack in a plate glass window stopping when it reaches a hole drilled on its path. All theorizing on this subject, at present, is purely speculative, but we feel justified in saying that according to our observations there is a definite "liking" between inclusions and graphite flakes.

We apologize for not giving a better description of our test pieces. The transverse test bars were 1.2-in. round and were broken on 12-in. centers.

We cannot add anything to Mr. Holtby's interesting remarks about manganese sulphide. Reactions occurring in the molten metal are very difficult to control and in the present work, no attempts were made to check them. The conventional chemical analyses of the raw material and of each melt are given in the paper. Beyond this there is no way of telling what was happening when the metal was molten.

MEMBER: I noted Mr. Ziegler said nothing about temperature measurements in his test of flowability. I think he should certainly say something about them in a study of this type. Also, I would like to

congratulate the authors on the fact that it seems to me that this is a rather interesting development in that they recognize the relationship between temperature and length of run as something besides a straight line. I think that they are on the right track.

MR. LORIG: Just a point in regard to the discussion of Mr. Ziegler. What I had in mind was the difference in the flowability of iron, for example, when superheated to 3,000°F. and cooled to 2800°F. and cast at 2800°F., as compared to the flowability of the same iron heated to 2800°F. and cast at 2800°F. In other words, there was quite a marked difference in flowability of iron when heated and cast in the two different ways. Why should two irons, both of the same composition, cast at the same temperature, behave differently if one is superheated and the other is not? It naturally brings up the question as to the cause for the difference.

MR. ZIEGLER: Thank you, Mr. Lorig, I didn't quite get your point. I see now what you mean. I am sorry that I did not say more about temperature measurements. We used an optical pyrometer. We measured the temperature of the melt in the furnace and also during the pouring of each mold. Of course, there was a certain error, but when the average temperature for each heat was used, the results were quite consistent and resulted in the curves presented in this paper.

A number of heats were repeated and the check always was reasonably satisfactory, so that we feel certain that all numerical values and observations presented in this paper are basically correct.

In conclusion it may be repeated that we used a high frequency furnace for making our melts. It takes 15 to 20 min. to melt 200 lb. of cast iron and another 10 to 15 min. to superheat it to 3000°F. The time periods are thus very short, and we suppose that if there are any chemical reactions, they are, under such experimental conditions, restricted to a minimum.

Synthetic Bonded Steel Molding Sands*

By Charles W. Briggs† and Robert E. Morey,**

Washington, D. C.

Abstract

From a simple sand mix consisting of washed silica sand, bentonite and water, it is possible to prepare synthetic green sands, synthetic dry sands and air dried sands, with excellent properties. The synthetic dry sand is prepared by merely oven drying the green sand molds. The addition of organic binders to green sand is also studied in detail.

Introduction

1. There are many kinds and varieties of steel molding sands being used by the industry today. These sands may be either natural bonded sands, semi-bonded sands, synthetic bonded sands, or mixtures of graded sands of any one of these. It may be seen that innumerable variations can thus be obtained. In one case, it is known that there are six steel molding sands in a shop, which in turn are prepared into 15 different mixes.

2. It is not necessary to have a variety of sands in order to produce a large number of sand mixes. For example, one grade of silica sand could easily be made up into a large number of synthetic sand mixes if it were so desired, and such a condition has been observed in commercial practice. If the number of sands could be reduced and the mixes simplified, greater care could be devoted to them with the result that a more scientific control would be maintained.

3. It is now fully appreciated by everyone connected with the manufacturing of castings that sand conditions may be responsible for defective castings. This realization has brought about the extensive use of sand control equipment in the foundry. When sand is moved, reclaimed, milled, rebonded and transported back to the molding floor on large scale plan, it is extremely difficult and economically unfeasible to have a number of sand mixes, each one requiring special attention. It is much more convenient to be able to shake out all sands at one place and maintain one backing sand that would have somewhat near the properties of the facing sand.

4. It would be extremely advantageous in a shop where both the green and dry sand methods of molding are used if simplification could be carried to the point that both synthetic green sand and synthetic dry sand molds could be made from approximately the same sand mix. The most simplified sand mix would consist of silica sand, water and a single bonding material. The question that now arises is—would this simplified mix be the proper sand for dry sand practice as well as for green sand practice? Of course, there is the possibility that it may not fulfill the requirements of either process.

5. In a study of commercial sand mixtures for both the green and dry sand practice it has been noticed that there are numerous additions of cereal type binders to the mix. In some cases there are as many as three different types; that is, sugar products, cereal products, and resinous by-products that are incorporated in the mixture in addition to the clay.

6. The question has been asked on numerous occasions as to just what mold properties were benefited by the addition of the cereal type binders. The answers have been quite varied and seldom agree. After a compilation of these opinions, it was found that in the case of green sands the cereal type binders were believed to increase the compression strength and the shear strength; that they did not reduce the permeability or sintering point, and that they were responsible for castings with a much improved surface appearance. These remarkable conditions were thought, in some cases, to be contrary to what would normally be expected.

7. It was therefore plain that further experimentation was needed on the subject of the cereal type binders. Thus the objects of the work undertaken were:

(1) To prepare a simplified synthetic green sand.

(2) To prepare a simplified synthetic dry sand.

(3) To study the properties of green sands when various cereal type binders were incorporated in the mix.

8. A survey of the literature on synthetic molding sands, bentonite and other clay binders, has been made and attention is called to the references and abstracts in the appendix.

Methods Used in Testing

9. All sand testing methods used in this investigation are in accordance with the standards and tentative standards of the American Foundrymen's Association, as set forth in the 1938 edition of "Testing and Grading of Foundry Sands and Clays."

Type of Sand

10. The sand used in this study was a washed and graded silica sand obtained from the New Jersey silica sand deposit. The sieve analysis is given in Table 1, and the distribution is shown in Fig. 1. The bonding material is bentonite (90 per cent through 200 mesh). Mixes are given in percentage of dry weight. Water is then added and reported as percentage of total weight.

11. All sands were mulled in a laboratory muller. The sand and bentonite were placed in the muller and mixed dry for one minute. Water was then added and the mixing continued for five minutes. The sand was then emptied into two quart mason jars, sealed, and allowed to temper 24 hours before testing.

Table 1

FINENESS TESTS OF THE SANDS USED IN THE INVESTIGATION

Sieve	Per Cent 53 Sand Remaining	Per Cent 63 Sand Remaining	Per Cent 78 Sand Remaining	Per Cent 108 Sand Remaining
6	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.06
20	0.30	0.04	0.00	0.00
30	0.94	0.26	0.00	0.02
40	3.90	2.72	0.06	0.04
50	14.74	12.50	1.16	0.04
70	54.90	38.44	18.70	1.04
100	23.32	31.78	50.18	25.80
140	1.40	11.54	24.00	45.02
200	0.10	2.22	5.30	22.18
270	0.02	0.30	0.68	4.38
Pan	0.04	0.22	0.20	2.12
A.F.A. Fineness No.	52.9	63.2	78.1	108.0
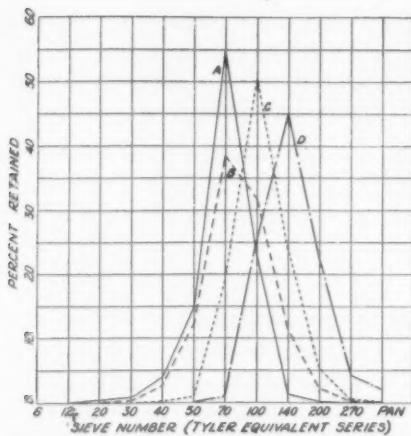
FIG. 1—DISTRIBUTION OF THE WASHED SILICA SANDS USED IN THE INVESTIGATION (A)—
A.F.A. FINENESS NO. 52.9 (B)—A.F.A. FINENESS NO. 63.2 (C)—A.F.A. FINENESS NO.
78.1. (D)—A.F.A. FINENESS NO. 108.0

Sand Tests

12. Sand tests for moisture, permeability and strength have been in common use for several years and are of known value. In some cases, however, a sand may have satisfactory values in these tests, yet still prove unsatisfactory in service. This led to the belief that sand had other important properties which influenced its behavior, but which were not detected by the tests in use. In this regard, it was thought by various sand investigators that the characteristics exhibited by the flowability and deformation of sand were definitely of interest and should be studied. Subsequent investigations resulted in the development of the flowability and deformation tests.

Flowability

13. Flowability is the property of sand which enables it to flow or conform to the shape of the pattern with a minimum of ramming or squeezing. It is measured on the A.F.A. sand rammer with an Ames dial attached in such a way that changes in length of the sand specimen for any blow of the rammer may be read. It is believed that a sand of good flowability will take the form of the standard sand specimen with the first few blows and that additional blows will cause very little change in length. A sand of poor flowability, however, will not compress as much on the first two or three blows, but will continue to decrease gradually for

several blows. After the fourth blow, a sand of good flowability will have taken the form of the cylinder and will show very little change in length when the fifth blow is struck. A sand of poor flowability, however, will not conform to the cylinder in four blows, and when the fifth is struck, a relatively large change in length takes place. The dial is attached so that the pointer can be set at zero after the fourth blow has been struck and read after the fifth blow. It is calibrated in percentage so that zero change in length equals 100 per cent flowability and a change in length of 0.1 inch equals zero flowability.[*1] Usual values are between 65 and 90 per cent. If flowability can be increased, castings will be improved and ramming decreased.

Deformation

14.   Deformation[2] is the change in length of the standard sand specimen between zero load in compression and the rupture load. In this test an Ames dial is attached to the strength testing machine so that a change in length of the specimen is indicated by the pointer as the load is applied. The pointer carries a rider which indicates the maximum deformation at rupture. The dial is calibrated to read deformation in thousandths of an inch per inch of specimen length. Sand should deform enough so that twisting or handling the flask or the pressure developed through the use of chaplets or core prints will not break the mold and yet the sand must not deform too much or the pressure of the metal will swell the mold cavity producing inaccurate castings and using unnecessary metal.

Resilience

15.   There has been established by certain experimenters a property which has been termed as sand resilience.[3] Sand resilience is defined as the product of compressive strength (in pounds per square inch) and deformation (in thousandths of an inch per inch of specimen length) times 1000. It is believed by these experimenters that the product of these two tests is a good indication of sand strength, particularly with respect to shock loads. It has been indicated in articles published on this subject[4] that a sand resilience value of less than 160 is normally found in green sand.

16.   The Dietert flowability indicator was used in the flowability tests and the Dietert deformation resilience accessory was

*1 Superior numbers refer to bibliography at end of paper.

used in the deformation tests. The Dietert mold hardness tester was
used in determining the hardness of the test specimens.

TEST RESULTS

Green Sand

17.   Starting out with the washed silica sand of an A.F.A.
grain fineness number of 63.2, a series of sand-bentonite-water
mixtures were prepared containing 4 per cent water with the
bentonite contents varying from 2 to 10 per cent. The test results
obtained under these conditions are illustrated in Fig. 2. It may
be noted that the permeability stays fairly constant over a wide
variation in bentonite content. Above 10 per cent bentonite, how-
ever, the curve falls off very rapidly. The green compression
strength increases as the bentonite content increases, though a
straight line relationship is not maintained. The green shear
strength also increases as the bentonite increases and in general
appears to be about 30 per cent of the green compression strength.
Numerous tests have shown that the compression test is more
reliable in that the shear test has been shown to be subject to
greater error.

18.   Continual work with these sands showed that the best
molding conditions were obtained when the sand had a green com-
pressive strength of from 4 to 6 lb. per sq. in. Fig. 2 shows that
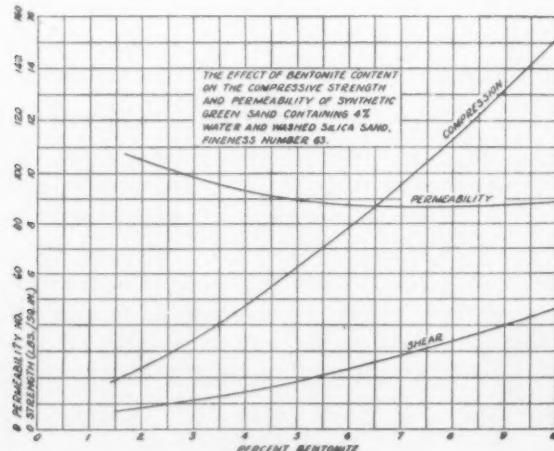
FIG. 2—EFFECT OF BENTONITE CONTENT ON THE COMPRESSIVE STRENGTH AND PERMEABILITY
OF SYNTHETIC GREEN SAND.

this condition can be attained by bentonite additions of 3.5 to 5.0 per cent when a moisture content of 4 per cent is used.

Moisture Content

19. The moisture content, as well as the bond content, has a very important effect on the properties of a sand-bentonite-water mixture. Mixes were therefore prepared containing 2, 4, 6, 8, and 10 per cent bentonite with added silica sand to bring the quantity up to 100 per cent. These mixes were then tempered to various moistures from 1 to 10 per cent, and tested for green compressive, strength, permeability, deformation, resilience, flowability, and weight of the specimen. The data obtained are recorded in Table 2 and plotted as functions of the moisture content on Figs. 3 to 7, inclusive. Since the various plates show the curves to be of some-what the same trend and varying mainly in the maximum values obtained, only one set of curves will be discussed in detail. Since 4 per cent bentonite is in the neighborhood of the amount of bond material usually found in commercial practice, this set of curves, Fig. 4, was selected for discussion.
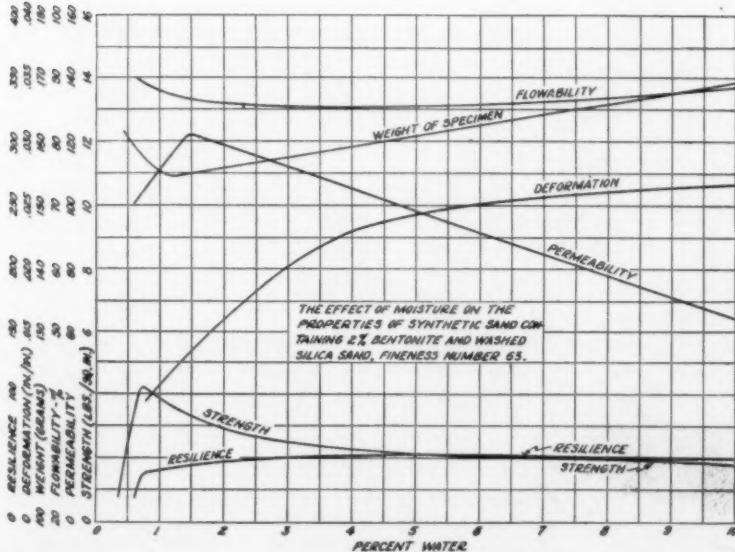
Fig. 3—Effect of Moisture on the Properties of Synthetic Sand Containing Two Per Cent Bentonite.

Table 2

SUMMARY OF TEST RESULTS

Bentonite	Water Per Cent	Weight of Standard Specimen Grams	Permeability	Compressive Strength	Flowability	Deformation In./in.	Resilience
2	0.80	157	106	3.18	89.0	.0006	80
2	2.00	156	119	2.92	86.0	.0144	42
2	3.88	159	106	2.29	85.5	.0229	51.5
2	5.66	162	95	2.07	85.8	.0234	48.4
2	7.08	165	80	2.35	86.6	.0243	57.1
2	9.22	168	70	1.89	85.2	.0291	54.2
4	0.84	162	79	6.15	90.2	.0114	70.2
4	1.14	158	80	8.19	87.4	.0111	91
4	2.26	156	90	6.33	83.9	.0168	106
4	4.10	160	105	4.61	85.0	.0270	125
4	6.00	163	90	3.96	84.4	.0280	111
4	7.60	166	81	8.90	84.1	.0300	117
4	9.20	169	68	3.64	85.4	.0298	108
6	1.34	164.5	57	8.94	90.2	.0097	86.7
6	2.66	158	58	10.11	80.8	.0195	197
6	1.94	159	98	10.98	82.8	.0191	211
6	4.04	161	73	7.35	82.2	.0324	838
6	5.68	165	87	6.82	81.3	.0318	520
6	7.72	169	74	6.01	88.3	.0337	202
6	9.58	178	55	5.49	88.9	.0338	185
8	1.94	161	43	14.82	84.8	.0102	151
8	2.52	161	71.5	18.86	81.2	.0141	196
8	4.50	161	73	10.76	85.2	.0265	286
8	6.28	166	83	8.77	80.3	.0388	296
8	8.50	166	69	7.83	82.0	.0410	321
8	10.40	176	50	7.57	81.6	.0411	311
10	2.16	168	85	15.88	87.9	.0089	78
10	2.56	163	84	15.64	81.5	.0116	182
10	4.44	160	51	14.38	72.5	.0216	855
10	4.98	161	83	13.33	73.8	.0288	884
10	6.80	166	80	11.14	76.3	.0377	420
10	10.06	177	67	9.23	79.2	.0435	401

FIG. 4—EFFECT OF MOISTURE ON THE PROPERTIES OF SYNTHETIC SAND CONTAINING FOUR PER CENT BENTONITE.
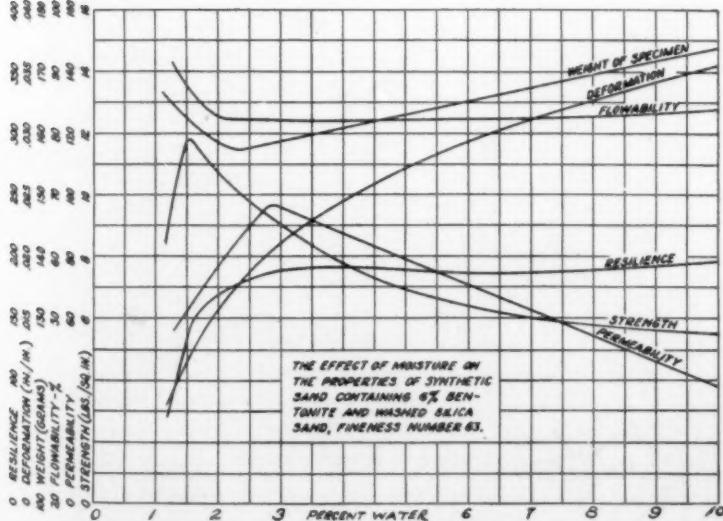
FIG. 5—EFFECT OF MOISTURE ON THE PROPERTIES OF SYNTHETIC SAND CONTAINING SIX PER CENT BENTONITE.
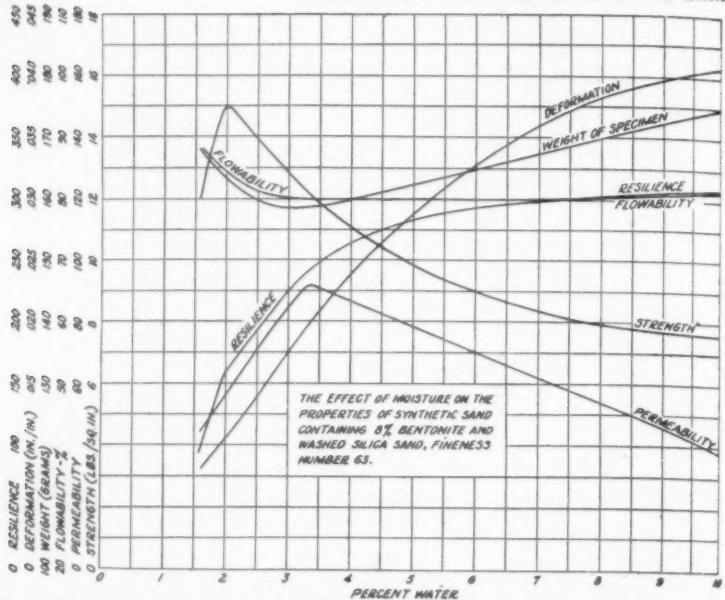
FIG. 6—EFFECT OF MOISTURE ON THE PROPERTIES OF SYNTHETIC SAND CONTAINING EIGHT PER CENT BENTONITE.
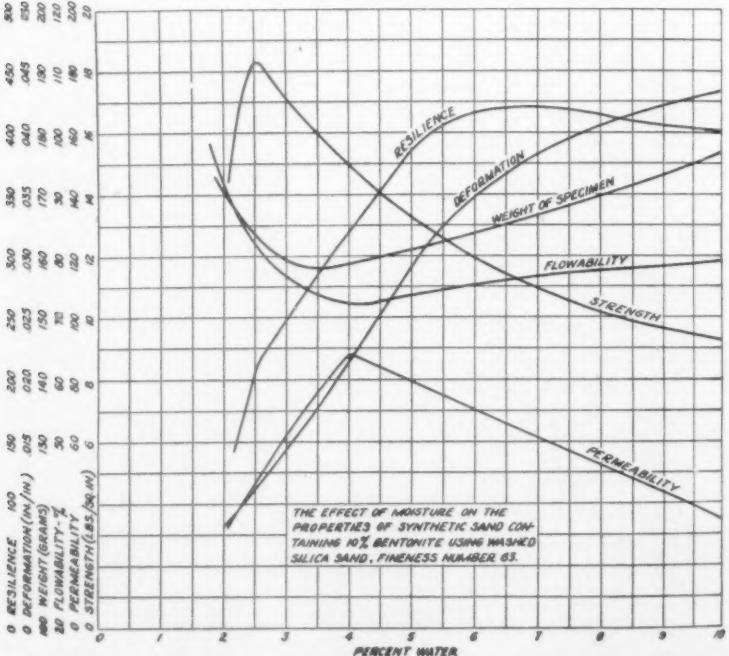

FIG. 7—EFFECT OF MOISTURE ON THE PROPERTIES OF SYNTHETIC SAND CONTAINING TEN PER CENT BENTONITE.

20.   It may be seen that as the moisture is increased the green strength rises rapidly until a maximum of 8.2 lb. per sq. in. is reached at 1.1 per cent moisture, which is the optimum moisture content with respect to strength for this mix. At this point, however, the sand is too dry to handle readily. With the addition of more water, the strength drops rapidly until the 6 per cent water content is reached, after which it falls more gradually. The term optimum moisture content has been used very loosely in many reports. From Fig. 4, it may be seen that the optimum points, with respect to different variables, occur at different moisture contents. It is obviously important, therefore, to state the variable tested when referring to optimum moisture content.

Permeability Curve

21.   The permeability curve has the same form as the strength curve. It rises rapidly as moisture is increased and reaches a maximum of about 107 at 2.1 per cent water, which is the optimum moisture content with respect to permeability. It is to be noted that the optimum moisture content with respect to permeability comes at a higher moisture content than the optimum moisture content with respect to strength. This appears to be the case with all synthetic sands. In natural sands,[3] the optimum moisture contents with respect to strength and permeability may come at the same moisture, or the optimum moisture with respect to permeability may be lower than the optimum with respect to strength. The last case is particularly true with sands containing a high percentage of silt. The large variation in strength and permeability with change in moisture serves to emphasize the importance of knowing the proper moisture to use for any sand and keeping it at that value.

22.   The flowability shows very little variation except for a sharp increase as the moisture is reduced below 2 per cent. The minimum flowability is 84 at 2.2 per cent water and this increases very slightly as the moisture is increased.

23.   The weight of sand necessary to make a specimen exactly 2 inches high has been plotted as "weight of specimen." This can be converted to the "rammed density" used in British sand research by dividing the weight of any specimen by its volume of 103 cubic centimeters. It is interesting to note that the weight bears a close relation to the permeability in that maximum permeability and the minimum weight occur at very nearly the same

moisture content. When the sand is either drier or wetter than
this optimum value, the weight increases and the permeability
decreases.

Deformation Curve

24. The deformation curve starts at a low value for low
moistures and rises very rapidly up to 0.0235 inch per inch at 4
per cent water, above which it rises more slowly. The steep slope
between 1 and 4 per cent, which includes most synthetic green
sands, indicates that moisture has a pronounced effect on deforma-
tion and, indirectly, on resilience. The low values of deformation
below 2 per cent water explain the weakness of green sand when
it is used too dry, even though the strength may be high.

Resilience Curve

25. The resilience, which is the product of strength and
deformation, resembles them. It starts at a low value, rises rapidly
to a maximum and then decreases slightly as moisture increases.
The break in the curve at 1.1 per cent water is the result of the
sharp maximum in the strength curve. The maximum resilience,
112, occurs at 3.0 per cent water, which is very close to the moisture
used in the average green sand.

26. From the curves developed on Figs. 3 to 7, inclusive,
composite graphs (Figs. 8 to 13) were prepared, showing how each
of the properties is affected by changes both in moisture and in
bentonite content.

Green Compressive Strength Curves

27. Fig. 8 shows the combined green compressive strength
curves as taken from Figs. 3 to 7. For each bentonite content there
is an optimum moisture content with respect to strength, which
gives a sharp maximum in the curve. As the moisture is increased
or decreased the strength falls rapidly. This graph may be used
to design green sand mixtures by drawing a horizontal line from
the desired green compressive strength value in the left margin to
the line labeled "optimum moisture with respect to permeability."
From this point the bentonite content is found by interpolating
between the nearest two bentonite curves and the moisture is ob-
tained by drawing a vertical line to the lower margin and reading
the moisture from the scale. This bentonite and moisture content
will produce the highest possible permeability at the desired
strength. The daily additions of bentonite may be computed by
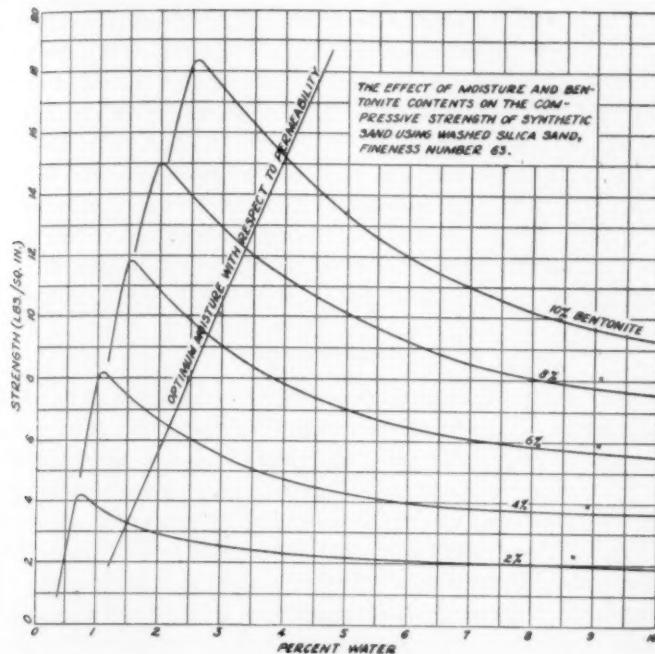
FIG. 8—EFFECT OF MOISTURE AND BENTONITE CONTENTS ON THE COMPRESSIVE STRENGTH OF SYNTHETIC SAND.

plotting the green strength and moisture content from daily tests on the graph. Interpolating between the bentonite curves gives the amount of effective bentonite in the mix and subtracting this amount from the amount which is desired in the sand gives the amount of bentonite which should be added to the sand to maintain its properties.

28. A study of sand conditions in steel foundries[4] has shown that in general, the green compression strength of sand varies from 2.5 to 11.5 pounds per square inch, depending on the type of molds desired. It may be seen that by varying either the moisture or the bentonite content, the above values may be obtained. The strengths most usually desired are from 4 to 6.5 pounds per square inch. This may be obtained with bentonite additions of from 3 to 5 per cent with 3 per cent moisture.

29. The foregoing statements refer to a washed silica sand with an A.F.A. grain fineness number of 63.2. In order to find the

effect of other grain sizes on the strength, three other sands, having
an A.F.A. grain fineness numbers of 52.9, 78.1, and 108.0 (see
Fig. 1) were tested with 4 per cent bentonite and various moisture
contents from 1 to 10 per cent. The results are shown on Fig. 15
(p. 672). From this it is seen that the coarse sands have the lowest
strengths. The graph appears to show one exception to this rule,
where the strength curve for the 63 fineness sand is slightly higher
than the curve for the 78 fineness sand between 2.9 and 4.8 per cent
moisture. This effect is believed to be due to the differences in
distribution of these sands as shown on Fig. 1.

SAND DISTRIBUTION

30. In order to understand the effect of sand distribution
more clearly, a comparison was made of a good and a poor sand
distribution. A quantity of sand was screened on the Tyler
standard screens and the sands retained on each sieve were kept
separate. From these sands, two sands were prepared having the
same A.F.A. grain fineness number but varying widely in distribu-
tion. A 96 per cent sand was mulled dry for one minute with 4 per
cent bentonite, then 3 per cent water was added and mixing con-
tinued for 5 minutes. The fineness analysis (by synthesis) and the
test results are shown in Table 3.

Table 3

COMPARISON OF A GOOD AND POOR SAND DISTRIBUTION

Sieve	Non-uniform Sand Poor Distribution Per Cent Retained		Uniform Sand Good Distribution Per Cent Retained
6	0		0
12	0		0
20	0		0
30	3.22		0
40	16.13		0
50	16.13		0
70	16.13		0
100	16.13		100.0
140	16.13		0
200	16.13		0
270	0		0
Pan	0		0
A.F.A. Fineness No.	70		70

Wt. of specimen	162 g.	150 g.	Decrease 7.4%
Green Perm.	69	86	Increase 24.7%
Green Compr.	6.04 lb./sq. in.	4.90 lb./sq. in.	Decrease 18.9%
Deformation	0.0225	0.0216	Decrease 4.0%
Resilience	136	106	Decrease 22.1%
Dry Perm.	95	120	Increase 26.3%
Dry. Comp.	174.7	133.4	Decrease 23.7%

31.   The sand with uniform grains has less strength. This amounts to an 18.9 per cent decrease in the green state and a 23.7 decrease in the dry state. The permeability increased 24.7 per cent in the green state and 26.3 in the dry state. The deformation was only 4 per cent less, but the resilience was 22.1 per cent less, due to the decrease in green strength. There was a decrease of 7.4 per cent in the weight of the specimen indicating that the uniform sand would have more voids and collapse more easily to prevent hot tears. The uniform sand had a much smoother surface and both were about equal in regard to rubbing off.

BENTONITE AND MOISTURE EFFECT ON PERMEABILITY

32.   Fig. 9 shows the effect of bentonite and moisture content on green permeability. The highest permeability (122) occurs with 2 per cent bentonite at 1.5 per cent water. As water is increased, permeability decreases as a straight line relation. When the water is decreased below 1.5 per cent, the optimum moisture with respect to permeability for this mix, the permeability falls sharply. The other curves are similar except that the maximum permeability is not so high and occurs at higher moisture contents as the bentonite is increased. The curves for 6, 8, and 10 per cent bentonite approx-

THE EFFECT OF BENTONITE AND MOISTURE CONTENTS ON THE PERMEABILITY OF SYNTHETIC SAND WITH WASHED SILICA SAND, FINENESS NUMBER 63.
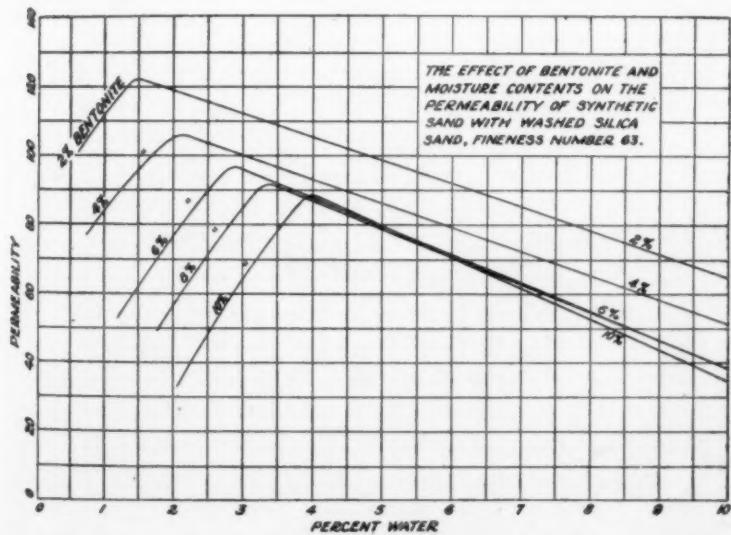
FIG. 9—EFFECT OF BENTONITE AND MOISTURE CONTENTS ON THE PERMEABILITY OF SYNTHETIC SAND.

imately coincide above 4 per cent water, indicating that increase in bentonite does not decrease permeability as might be expected.

33. If a higher permeability than that shown on this chart is desired, recourse must be made to a sand of a larger grain size. The manner in which changes in A.F.A. grain fineness number affect the permeability under conditions of 4 per cent bentonite and varying moisture additions may be seen in Fig. 15 (p. 672). In this manner, it may be noted that it is quite possible to obtain a desired permeability by varying the grain size and maintaining close control of the particle distribution.

34. Fig. 10 shows the effect of bentonite and water contents on the weight of sand necessary to produce a specimen exactly 2 inches high. For each bentonite content there is a moisture content which produces a minimum weight. As the bentonite is increased, this minimum weight occurs at higher moistures. When these weights are divided by the volume of the specimen (103 cubic centimeters) the rammed density is obtained. From the rammed density scale it is seen that it varies from 1.50 to 1.72 while, in every case, the ramming energy was the same.

35. The variation in weights in Fig. 10 shows that by selection of the proper moisture content a sand can be made which, under uniform conditions of ramming, will weigh less per unit
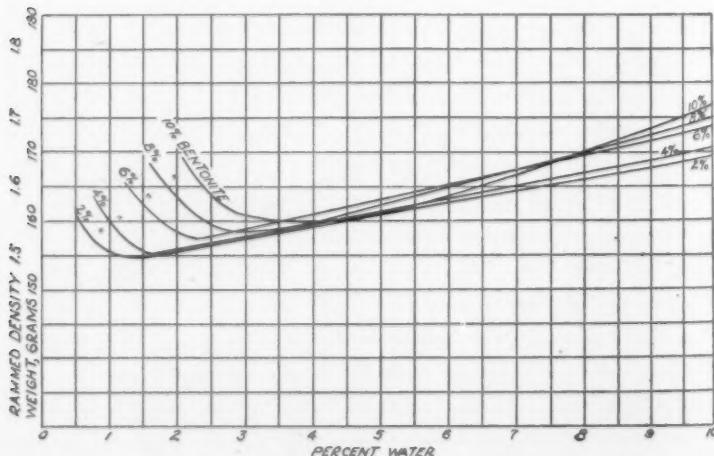
FIG. 10—EFFECT OF BENTONITE AND MOISTURE CONTENTS ON THE WEIGHT OF THE STANDARD TEST SPECIMEN. DIVIDING THE WEIGHT OF THE SPECIMEN BY THE VOLUME GIVES THE RAMMED DENSITY USED IN BRITISH SAND TESTS.

volume than the same sand at higher or lower moisture contents. While this sand will have similar strength, it will contain more voids and will be more flexible as the metal cools and contracts. In this regard, it is therefore suggested that the proper selection of moisture content may be a factor in the prevention of hot tear defects and blind scabs. Recent[5,6,7,8,] articles have suggested other means of attaining the same results. In one method sawdust was mixed with the sand. It accomplished the purpose of allowing the sand to contract or "give" as the metal contracted but it produced an objectionably large volume of gas.

Steel Sand Flowability

36.　Fig. 11 shows the effect of bentonite and water contents on flowability. The flowability decreases slightly as bentonite is added up to 8 per cent. Above 8 per cent a rather sudden drop is recorded. Using the sand very dry increases the flowability regardless of the amount of bentonite. This relation is likewise true when the moisture content is high.

37.　Previous experimentation has shown[4] that a steel foundry sand should be maintained at a flowability of at least 75 per cent, and that the average sand will fall between 75 or 80 per cent. A mix composed of washed silica sand, bentonite, and water has excellent flowability as may readily be seen on Fig. 11, where, in practically all mixes, it falls within the range of 80 to 90 per cent.

THE EFFECT OF BENTONITE AND MOISTURE CONTENTS ON THE FLOWABILITY OF SYNTHETIC SAND, USING WASHED SILICA SAND, FINENESS NUMBER 63.
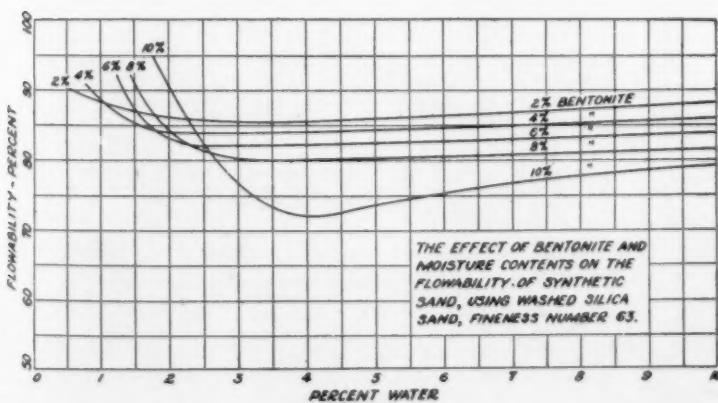
Fig. 11—Effect of Bentonite and Moisture Contents on the Flowability of Synthetic Sand.

BENTONITE AND MOISTURE CONTENT ON DEFORMATION

38. The effect of bentonite and moisture content with a washed silica sand of 63 fineness on the deformation value is shown in Fig. 12. Deformation values are low for low moisture contents, but increase as moisture increases. The increase, however, is more pronounced when the bentonite content is high. The curves have a common intersection at about 4 to 4.5 per cent water.

39. The previous experimenters on the subject of deformation have not set any special limits to this property that would define just what deformation value a good molding sand should have. In general it appears that the deformation test has been used merely as a step in the calculation of the resilience. Dietert[4] and his co-workers found that commercial green sands for steel castings had deformation values running from 0.009 to 0.038 inch per inch. The data presented in Fig. 11 show that it is possible to obtain with sand-bentonite-moisture mixes values from 0.010 to 0.040 inches per inch of specimen length.

THE EFFECT OF BENTONITE AND MOISTURE CONTENTS ON THE DEFORMATION OF SYNTHETIC SAND, USING WASHED SILICA SAND WITH A FINENESS OF 63
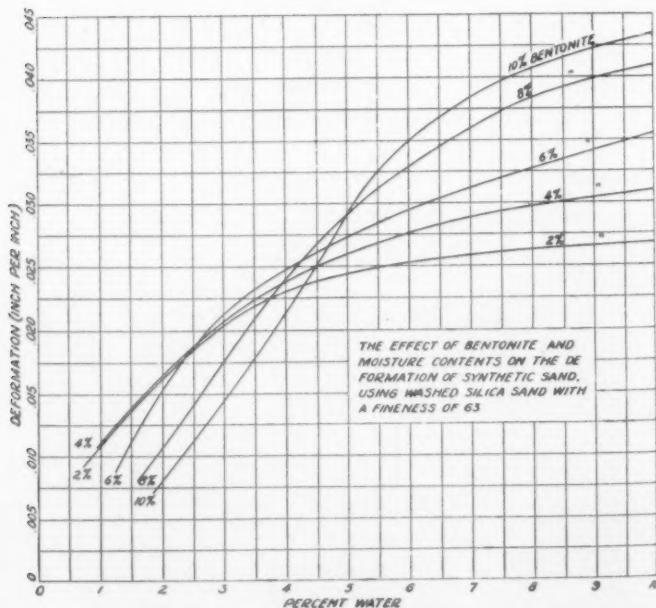
FIG. 12—EFFECT OF BENTONITE AND MOISTURE CONTENTS ON THE DEFORMATION OF SYNTHETIC SAND.
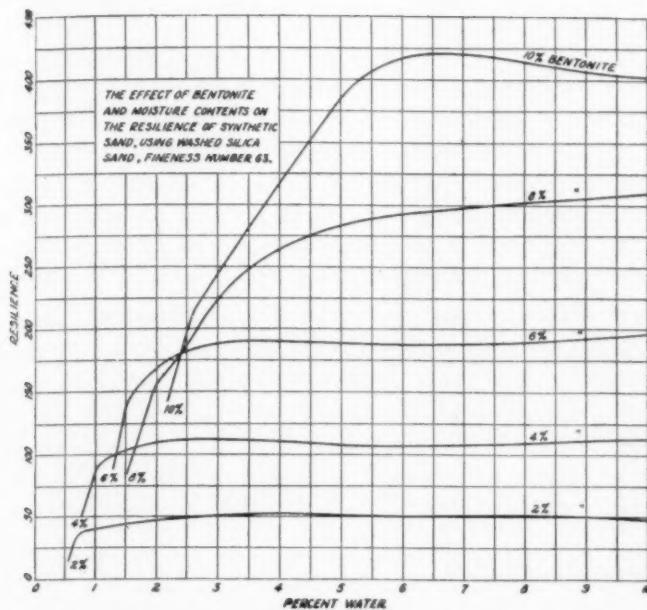
Fig. 13—Effect of Bentonite and Moisture Contents on the Resilience of Synthetic Sand.
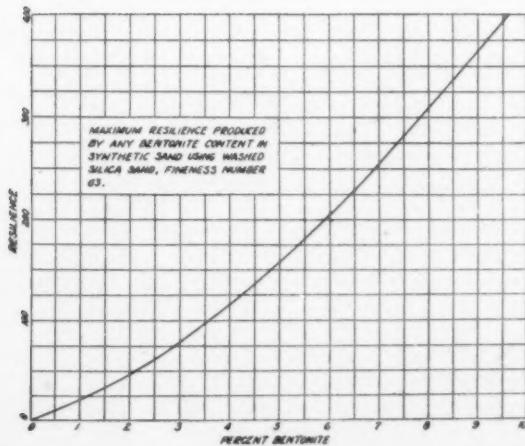
Fig. 14—Maximum Resilience Produced by Any Bentonite Content in Synthetic Sand.

RESILIENCE VALUES

40.   On Fig. 13 are plotted the resilience values. From these curves it may be seen that the maximum resilience produced by:

2 per cent bentonite is 53	8 per cent bentonite is 310
4 per cent bentonite is 113	10 per cent bentonite is 422
6 per cent bentonite is 197	

These values are plotted in Fig. 14 from which it is possible to find the minimum bentonite content necessary to produce any desired resilience.

41.   The importance of the resilience property has been previously discussed but here again it has been found that no limits have been set as to satisfactory values. Again reference is made to Dietert, Woodliff, and Schuch,[4] who have shown values from 61 to 238, the average of 24 different steel sands being 135. These authors have explained that for green sand work the value is normally less than 160. Just what the lower limit for resilience in steel sands should
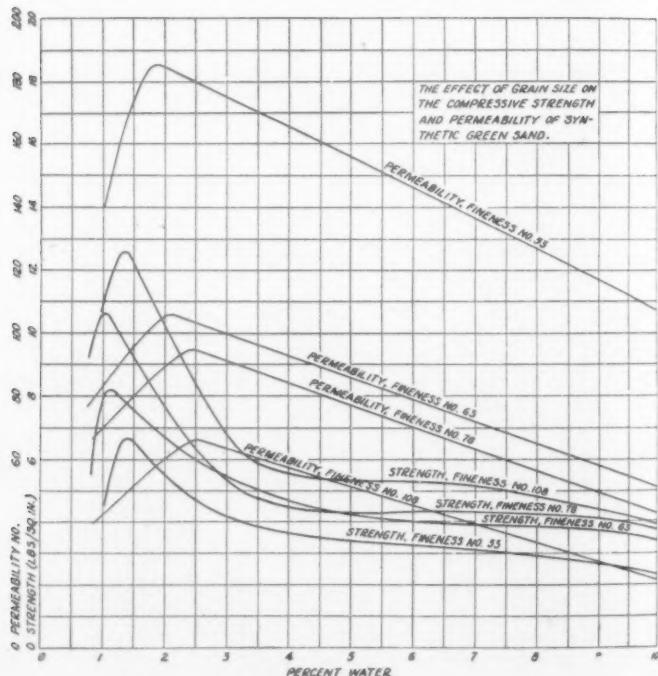
FIG. 15—EFFECT OF GRAIN SIZE ON THE COMPRESSIVE STRENGTH AND PERMEABILITY OF SYNTHETIC GREEN SAND.

be has not been stated. It may be seen, however, from Fig. 13, that values from 50 to 400 may be obtained by the simplified sand-bentonite-water mixtures, and they will therefore fulfill any requirements set up in this regard.

Sintering

42. The sintering points of silica sand-bentonite mixes are of a high value. A mixture of A.F.A. number 63 fineness washed silica sand with 5 per cent bentonite and 5 per cent water, thoroughly baked and cooled, showed the following test data:

    1275°C. (2327°F.)   no sinter
    1300°C. (2372°F.)   incipient sinter
    1325°C. (2417°F.)   definitely sintered (sinter point)

A mixture of silica sand of A.F.A. fineness number 123 with 6 per cent bentonite and 6 per cent water gave the following results:

    1275°C. (2327°F.)   no sinter
    1300°C. (2372°F.)   incipient sinter
    1325°C. (2417°F.)   definitely sintered (sinter point)

These sintering values compare very favorably with the best that are obtained in steel molding sands, since 1250°C. (2282°F.) appears to be an average value.

Dry Sand Properties

43. It was planned to study the dry sand properties of the green sand mixtures so that if it were found desirable to use the

Table 4

Summary of Tests for Dry Strength and Permeability

Bentonite	Moisture Per Cent	Dry Compressive Strength lb. per sq. in.	Dry Permeability No.
2	2.00	25.4	138
2	2.66	81.9	163
2	4.38	103.9	167
2	7.88	114.0	171
4	1.60	48.6	118
4	3.24	101.1	163
4	8.10	140.2	161
6	2.66	90.3	134
6	5.56	190.1	169
6	9.58	184.2	120
8	1.76	20.0	85
8	4.00	133.1	167
8	5.90	179.2	171
8	8.20	206.1	156
10	2.56	29.2	69
10	3.28	66.8	124
10	5.20	165.9	185
10	7.81	255.9	152
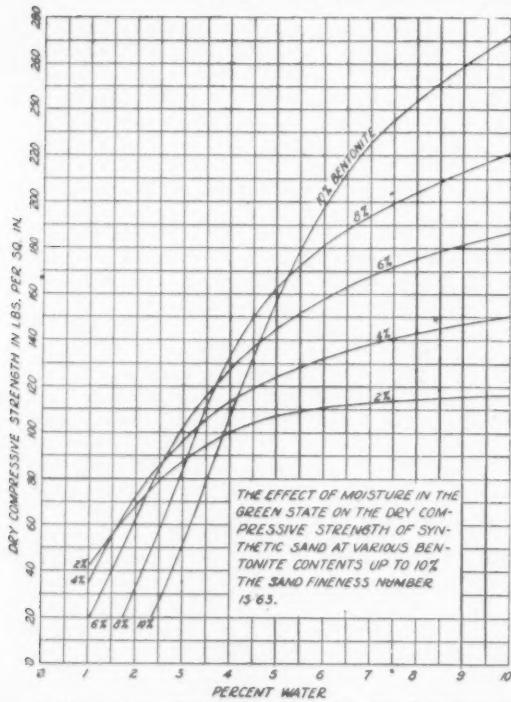
The effect of moisture in the green state on the dry compressive strength of synthetic sand at various bentonite contents up to 10% the sand fineness number is 63.

FIG. 16—EFFECT OF MOISTURE IN THE GREEN STATE ON THE DRY COMPRESSIVE STRENGTH OF SYNTHETIC SAND.

The effect of moisture in the green state on the dry permeability of synthetic sand at various bentonite contents up to 10% the sand fineness number is 63.
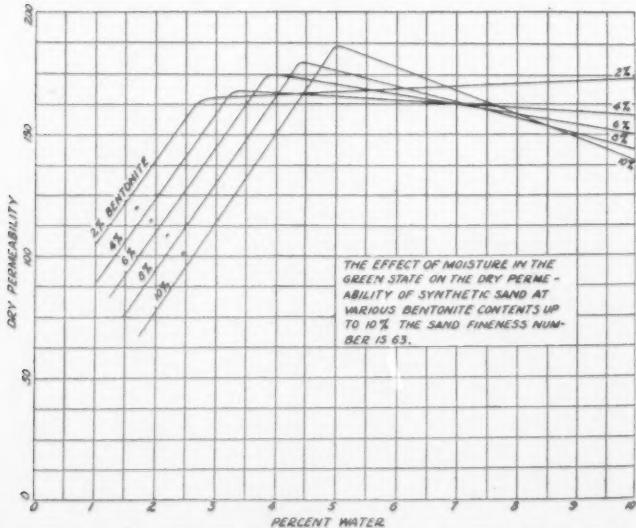
FIG. 17—EFFECT OF MOISTURE IN THE GREEN STATE ON THE DRY PERMEABILITY OF SYNTHETIC SAND.

dry sand practice, it could be accomplished without changing to a different sand or mix.

44.   Sand-bentonite-water mixtures were made and tested for dry strength and dry permeability. The specimens were dried at 110°C. (220-230°F.), cooled in a dessicator and tested. The results are shown in Table 4 and plotted on Figs. 16 and 17. From Fig. 16 it may be seen that dry strength increases rapidly, as the moisture in the green state is increased. High bentonite contents (8 to 10 per cent) produce very high strengths when the moisture content is high, but at low moisture contents they produce less dry strength than low bentonite mixtures. From the graph it may be seen that the simplified silica-bentonite-water mix will produce any desired strength from 20 lb. per sq. in. to 250 lb. per sq. in. by using suitable bentonite and water contents. Since the usual range of dry strengths is from 75 to 150 lb. per sq. in. the simplified sand will satisfy the requirement for dry strength.

Dry Permeability

45.   The dry permeability values from Table 4 are plotted on Fig. 17. As in the case of green permeability the dry permeability has a maximum at some definite water content. As the moisture is increased or decreased, the dry permeability decreases approximately as a straight line function. In general, it requires about 1 per cent more water to produce the maximum dry permeability than it does to produce the maximum green permeability.

46.   Considerable difficulty was experienced in obtaining consistent results in the tests for dry strength and dry permeability. Slight variations in procedure produce unreasonably large variations in results. The highest and most consistent results were obtained when the samples were mulled and passed through a 1/4 inch sieve, then placed in a two quart mason jar as quickly as possible. From this jar 50 grams of sand were then weighed out in a pan, placed in the Dietert moisture teller, and heated for at least three to six minutes, depending on the amount of water present. The pan was then placed in a desiccator to cool to room temperature. When cool, the pans were removed from the desiccator and weighed immediately. In this way, close checks on moisture contents were possible. In the meantime, cylinders were made for the dry strength and dry permeability tests. It was found that the slightest trace of moisture in the dried specimen had a large effect on test results so

the cylinders were baked for several hours (3 to 8, depending upon
the moisture content) and were then removed from the oven and
placed in a desiccator to cool. At least two hours was allowed for
the specimens to reach room temperature. Cooling can be acceler-
ated by directing an electric fan at the outside of the desiccator.

47.   Table 5 was taken from Fig. 16 and shows the water
contents necessary to produce the dry strengths in the first column.
Eighty pounds per square inch dry compression, for example, is

Table 5

PERCENTAGE OF WATER AND BENTONITE NECESSARY
TO PRODUCE ANY DRY STRENGTH

Dry Strength Pounds per sq. in.	Per Cent Water Bentonite, Per Cent Used				
	2	4	6	8	10
20	. . .	. . .	1.06	1.76	2.37
40	. . .	1.13	1.51	2.17	2.80
60	1.66	1.65	1.96	2.56	3.19
80	2.57	2.29	2.39	2.94	3.54
100	4.00	3.18	2.93	3.30	3.89
120	. . .	4.50	3.66	3.68	4.26
140	. . .	7.40	4.70	4.20	4.65
160	. . .	. . .	6.22	4.88	5.07
180	. . .	. . .	8.74	5.95	5.54
200	. . .	. . .	. . .	7.58	6.10
220	. . .	. . .	. . .	9.90	6.80
240	. . .	. . .	. . .	. . .	7.78
260	. . .	. . .	. . .	. . .	9.08

produced by 2 per cent bentonite at 2.57 per cent water; 4 per cent
bentonite at 2.29 per cent water; 6 per cent bentonite at 2.39 per
cent water; 8 per cent bentonite at 2.94 per cent water; 10 per
cent bentonite at 2.94 per cent water; 10 per cent bentonite at 3.54
per cent water. The dry strength values were then marked on the
corresponding bentonite curves on Fig. 8 at the proper moisture
contents to produce the combined green and dry strength graph
shown in Fig. 18. In this graph any silica-bentonite-water sand
mix having a washed silica sand with a fineness of 63 for a base is
represented by a point. The graph shows four variables; bentonite
content, water content, green strength and dry strength. When
any two of these are known, the other two can be found.

Example 1.   A mix is desired with a green strength of
6 lb. per sq. in. and a dry strength of 100 lb. per sq. in. Draw-
ing a horizontal line on Fig. 18 from 6 lb. per sq. in. on the
left margin until it intersects the 100 lb. per sq. in. dry

strength line, locate a point. Interpolating between the 4 and 6 per cent bentonite lines shows that a bentonite content of 4.4 per cent is needed. Drawing a vertical line down to the lower margin, shows that a water content of 3.07 per cent will be required.

Example 2. It is desired to maintain a bentonite content of 5 per cent in a sand. If a test shows 5.4 lb. per sq. in. at 3.5 per cent moisture after several heats, find the bentonite necessary to bring the heap back to the desired value. Plotting the test values, 5.4 lb. per sq. in. and 3.5 per cent water on Fig. 18, gives a point which indicates that there is approximately 4.2 per cent of effective bentonite in the heap. Therefore, 0.8 per cent bentonite must be added.

48. From Fig. 18 it may be seen that a dry sand of any desired property may be obtained. The dry strength desired should be decided upon first. It is evident that several percentages of benton-
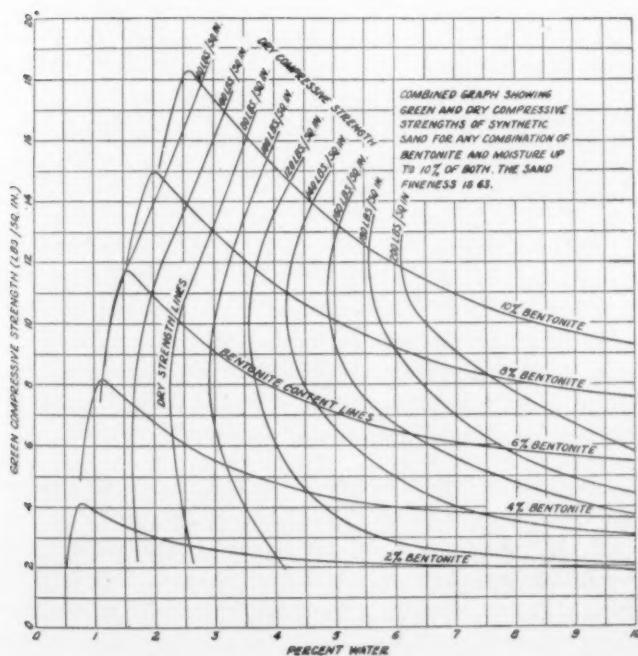
FIG. 18—GREEN AND DRY COMPRESSIVE STRENGTHS OF SYNTHETIC SAND.

ite will produce the desired dry compression strength, but some point on the dry compression strength line should be selected where the bentonite, moisture, and green strength have suitable values. By this it is meant that the bentonite content should not be too high or the mix will be sticky and expensive; the water content should not be too high or the mix will be low in flowability and green strength, and will take a long time to dry; also, the green compression strength should be such that the sand is workable in the green state.

49.   It is believed, however, from the above data, that a suitable dry sand can be produced from the synthetic green sand that is in use by increasing the moisture content when the sand is being mulled. Thus a simplified procedure has been established for the preparation of dry sand molds by the use of a simplified synthetic green sand.

Air Dried Sands

50.   The drying of green sand molds in air is a method of production that is used somewhat extensively, although the properties of air dried mold are not so well known. Air drying may in many cases be substituted for oven drying and produce even better results, provided it is not necessary to obtain the high strengths that are associated with dry sand molds. Air drying takes from one to four hours, though an overnight drying time is not detrimental, and in some cases it is desirable.

51.   In both dry sand molds and air dried sand molds, the moisture at the mold face is very low when the molds are poured, so there is practically no steam generated for perhaps the first two minutes. By the time the heat penetrates far enough into the mold to produce steam, the initial skin formation of the metal[9] will be sufficient to resist the back pressure of the steam, provided the mold has some reasonable measure of permeability.

52.   Resistance to contraction, of course, is not as great in air dried molds as in oven dried molds. Also, it is much easier to remove and clean castings from air dried molds. When properly made, air dried molds have a smooth hard surface, free from checks and cracks. When the molds are closed they will fit tightly and prevent the occurrence of fins, which are so common in oven dried molds.
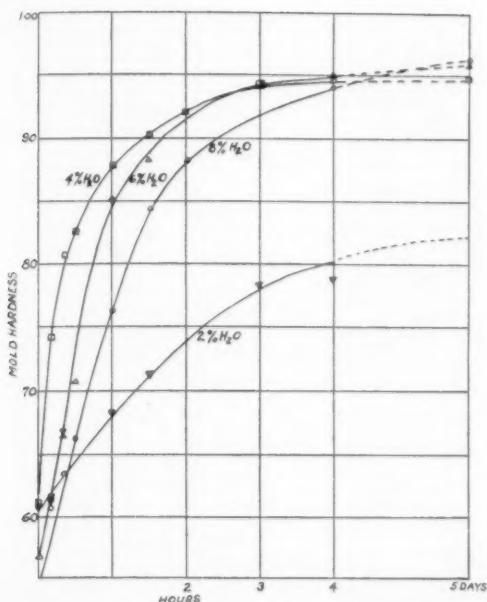
Fig. 19—Mold Hardness Obtained with Various Percentages of Moisture. Silica Sand A.F.A. No. 63 Fineness Bonded with Four Per Cent Bentonite.

53. The rate of air drying depends upon the time, temperature, humidity, air circulation, moisture content, permeability, size of the mold, and fineness of the sand. Of these variables, the drying time and the moisture content are the most effective in controlling the mold surface.

Mold Hardness Test Results

54. In Fig. 19 the results are shown of mold hardness tests made on four mixtures of synthetic sands containing 4 per cent bentonite and 2, 4, 6, and 8 per cent water. The sand containing 2 per cent moisture was much too dry to develop a good hardness on air drying. In regard to the 4, 6, and 8 per cent moisture, it may be seen that the higher the moisture content, the slower is the development of the mold hardness, but that eventually (2 to 5 days) a higher ultimate hardness is obtained. Thus if fast air drying is necessary, the 4 per cent moisture mix should be the one adopted, whereas if the molds will remain open for more than a day or two, the higher moisture contents may prove the most satisfactory.
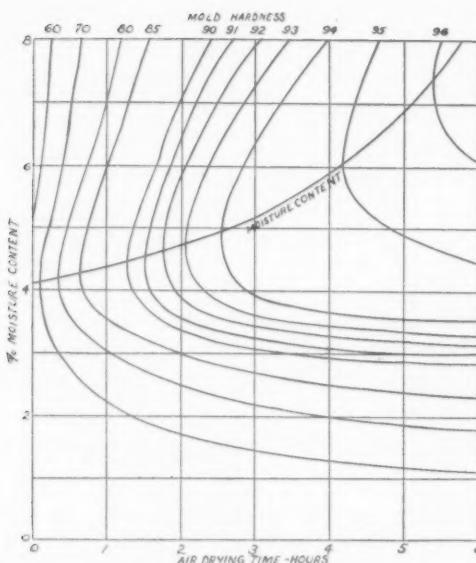
FIG. 20—MINIMUM AIR DRYING TIME TO OBTAIN MOLD HARDNESS. SILICA SAND A.F.A. FINENESS NUMBER 63, BONDED WITH FOUR PER CENT BENTONITE. TO OPERATE CURVES SELECT A DESIRED HARDNESS. DRAW A VERTICAL LINE FROM INTERSECTION OF HARDNESS LINE AND MOISTURE CONTENT LINE TO FIND MINIMUM DRYING TIME. DRAW A HORIZONTAL LINE FROM SAME POINT TO FIND MOISTURE CONTENT NECESSARY.

55.   From the data of Fig. 19, the curves of Fig. 20 were constructed. This graph shows the time and moisture content necessary to obtain a given hardness when a washed silica sand of a fineness number of 63.2 was used, bonded with 4 per cent bentonite. It will be observed that for any given hardness there is a minimum time in which it may be produced, and a definite moisture content which must be used. These combinations locate the moisture content line.

CEREAL BINDERS

56.   Very often other materials are mixed with the sand to speed up the drying process. In Fig. 21 there is shown the effect of substituting 1 per cent of organic binder for 1 per cent of bentonite. The moisture content was maintained at 4 per cent. The addition of the cereal type binders produced greater hardnesses and produced these hardnesses sooner than was obtained in the straight bentonite mix.
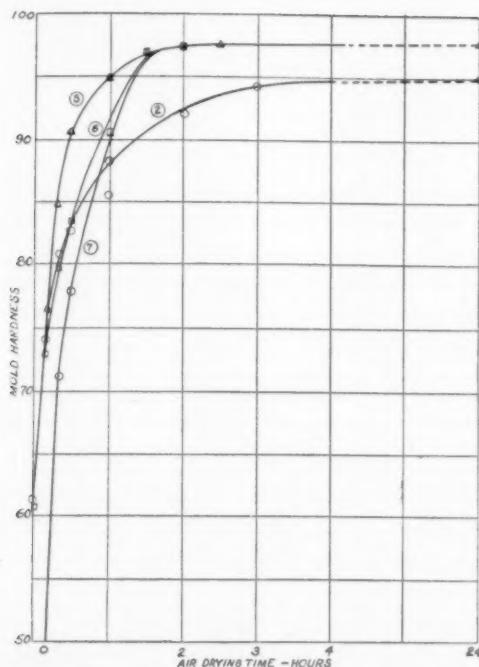
Fig. 21—Mold Hardness Obtained with Various Binders. Silica Sand A.F.A. No. 68 Fineness, Moisture Content Four Per Cent, Curve (2) Four Per Cent Bentonite. Curve (5) One Per Cent Dextrin, Three Per Cent Bentonite. Curve (6) One Per Cent Kordek. Curve (7) One Per Cent Bindex.

57. The value of these organic binders is somewhat doubtful, for in the first place air dried molds usually stay open for three or four hours and in many cases longer; thus, the increase of 3 to 5 points in hardness that can be obtained by using the organic binders may be of actually little commercial value. It is difficult to prove this point, as the writers know of no test that correlates mold hardness with its ability to resist erosion or spalling by the action of the molten metal. Some preliminary experiments have been performed at this laboratory which show that cereal binders do produce large quantities of gas when brought in contact with molten metal; thus sands must be considerably more permeable to prevent pinhole porosity.

58. The green compression strength of sands containing cereal binders is reduced, and the presence of the organic binders makes the sand sticky, allowing it to adhere to the patterns so that

the mold surface is not as smooth as when bentonite is used alone. It is thus felt that it is not necessary to complicate the green sand mix by the addition of cereal binders to increase the mold hardness of air-dried sand molds.

Cereal Binders in Synthetic Green Sands.

59. It has been stated previously that a large number of commercial green sand mixes contain one or more of the cereal type binders in addition to clay or bentonite. There also appears to be some doubt as to their effect on the properties of green sand. This latter point was studied in regard to an A.F.A. number 63.2 fineness washed silica sand.

60. Cereal type binders fall into three classes: cereal or sugar by-products, the resinous or lignone by-products, and the drying oils. Representative binders of all these classes were studied.

61. In an effort to ascertain the actual properties imparted to a synthetic green sand by these materials, batches were mixed containing 4 per cent of the various binders with 3 per cent water

Table 6

MOLD HARDNESS PRODUCED BY VARIOUS BINDERS IN GREEN SAND

Silica Sand, Fineness	Per Cent Bentonite	Other Binder	Per Cent Water	Mold Hardness
63.2	4	None	3	61.3
63.2	3	Dextrin 1%	3	60.9
63.2	3	Kordek 1%	3	60.7
63.2	3	Bindex 1%	3	30.8

and washed silica sand of fineness number 63. These mixes were tested for green permeability, green compression strength, and green shear strength. The results obtained from testing are set forth in Table 7. It is interesting to note that the green strength of bentonite far exceeds that of any other binder. In the permeability test the bentonite is exceeded only by Mogul. The strength of Mogul, however, was so low that it fell to pieces before it could be tested for compression strength. Bentonite may be said to have the highest permeability of any workable binder tested.

62. In order to ascertain if there were any advantages in combining the binders with bentonite, several mixes were made of various binders with bentonite at a moisture content of 3 per cent. These results are illustrated in Fig. 22. On the left ordinate is

plotted the strength of the 4 per cent bentonite mix without additional binders. The right ordinate shows the green compressive
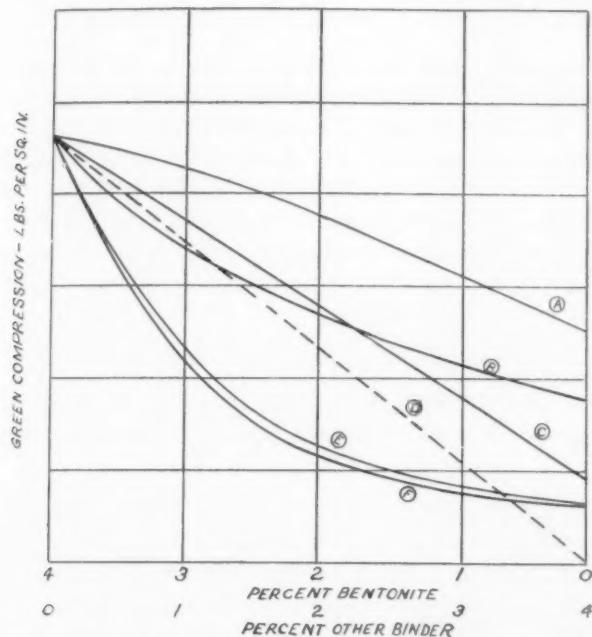
Fig. 22—The Effect of Substituting Organic Binder for Bentonite, Keeping the Total Binder Constant at Four Per Cent. Total Binder is Equal to Four Per Cent, Moisture is Equal to Three Per Cent. Silica Sand Fineness No. 63.2 Curve A Dextrin Used. Curve B Truline Used. Curve C Kordek Used. Curve D Bentonite Used. Curve E Bindex Used. Curve F Goulac Used.

Table 7

Strengths of Binders in Synthetic Green Sands

Binder	Green Permeability	Green Compression	Green Shear
Bentonite	128	4.67	1.29
Dextrin	90	2.50	0.80
Truline	91	1.78	0.62
Kordek	95	0.90	0.35
Liquid Bindex	127	0.71	0.31
Glutrin	121	0.65	0.30
Bindex	114	0.64	0.28
Goulac	126	0.61	0.28
Mogul	185	Very Low	Very Low
Core Oil	85	0.33	Very Low
Linseed	67	0.22	Very Low

strength of the various binders without bentonite. The dotted line
is the green compressive strength resulting from sand-bentonite-3
per cent water mixes in which bentonite varied from 0 per cent
to 4 per cent.

63. In every case the green compression strength decreases
as the organic binders are substituted partially or wholly for benton-
ite. In the case of the resinous or soluble binders, the strength of
the bentonite and organic binder combined is even less than the
strength of the bentonite portion of the binder would produce by
itself. This means that the soluble organic binder not only does
not produce any green strength, but it actually decreases the
strength that the bentonite would produce.

SINTERING OF CEREAL BONDED SANDS

64. Sintering points have been obtained on several green
sands prepared with cereal binders, and the following results are
typical:

Glutrin 4 per cent, A.F.A. No. 63 silica sand.
    1225°C. (2237°F.) no sinter
    1250°C. (2282°F.) sintered (sinter point).
Kordek 4 per cent, A.F.A. No. 63 silica sand.
    1225°C. (2237°F.) incipient sinter
    1250°C. (2282°F.) definitely sintered (sinter point).

The above data points to the fact that cereal bonded sands have a
sintering point (approximately 125°F.) below that of the bentonite
bonded sands.

65. It has been previously stated that organic binders do not
improve the mold surface. In most cases, because of their slightly
sticky characteristics, they adhere to the pattern.

MOLD HARDNESS OF GREEN SAND

66. Four mixes were tested for green sand mold hardness
(Table 6). Sand bonded with bentonite had in all cases the greater
hardness. The substitution of 1 per cent of Bindex, a soluble binder,
for 1 per cent of bentonite reduced the mold hardness 50 per cent.

67. The above results tend to indicate that the organic binders
have little, if any, beneficial effect upon the properties of synthetic
green sand. As a class, they do not increase the green permeability,

green compression and shear strengths, or green mold hardness; neither do they improve the workability of the sand or surface finish of the mold. Therefore, it appears that their presence in a green synthetic sand mix is not necessary, for they only complicate the mix.

68. It has been suggested that cereal binders help to prevent the green sand from drying out before the sand can be worked into molds. It is believed that the remedy for this condition is two-fold. In the first place, more water can be added when it is known that mixed sand must stand for periods before molding. In the second place, it is believed that too coarse a sand is being used. If the cereals are omitted, less gas is produced as will be shown in the next section, and hence, a less permeable sand is needed; therefore a finer sand may be used, which of course dries out more slowly than a coarse sand. At the same time, a finer sand will carry more water because it has more surface.

Evolution of Gas From Sand

69. It has been thought for some time that gas produced in the sand by the heat of the molten steel is responsible for pin hole and possibly blow hole defects. The molten steel turns all the available moisture into steam with the possibility that some of it is changed to hydrogen and oxygen.

70. Organic binders such as molasses, linseed oil, core oils, pitch, resin, cereal binders and other hydrocarbon compounds form gases of carbon or methane under the action of the high temperatures of molten steel.

71. The clay content of the molding sand, which is usually a hydrated aluminum silicate or iron oxide, will become dehydrated under the action of the heat and the water will be converted into steam. The steam pressure forces the gases generated into the backing sand. If, however, the backing sand is not very permeable, then the gas is confined and as the pressure builds the gas enters the casting through the thin envelope of solidified steel. It can easily be seen that the more gas that is generated, the greater is the opportunity for the formation of pin hole defects. One of the best preventive measures for such a situation is to use a molding sand, which at high temperatures will generate a minimum amount of gas.

72. It was decided that an investigation along these lines would indicate the amount of gas that is being generated in molds.

TEST MOLD

73. Tests were made using a standard 2-in. sand specimen rammed in a $5\frac{1}{2}$-in. length of 2-in. iron pipe in the standard rammer. The open end of the pipe was then closed with a pipe cap into which was threaded a $\frac{1}{4}$-in. pipe nipple. The tests were made by ramming six specimen tubes in a mold and pouring steel into it so that the face of the sand specimen was against a 1-inch section of steel in such a manner as to seal the tube and trap the gas generated in the tube. The gas passed off through the nipple and was collected and measured by displacement of water (Fig. 23).

74. In order to find the effect of the moisture content of the sand on the amount of gas generated, three samples were made, each with 6 per cent bentonite, and were tempered with 2, 6, and 10 per cent water. Fig. 24 shows the results. The cumulative volumes of gas are plotted as a function of time. From this graph it may be seen that the volume of gas increases slightly with increase in water content. It is interesting to note that when the water content of the specimen was 10 per cent, steam was forced through the 2-in. specimen in about $2\frac{1}{2}$ minutes and passed on into the collecting bottles, while in the specimens with less moisture the steam pressure was less and most of the moisture recondensed in the sand.

75. In order to find the effect of bentonite on the amount of
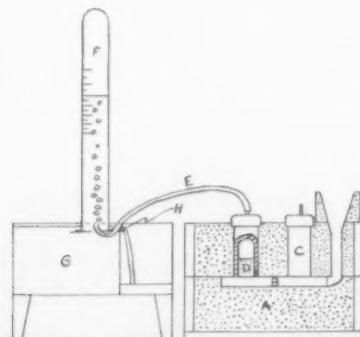
FIG. 23—APPARATUS USED TO MEASURE GAS PRODUCED IN SAND. A. SAND MOLD. B. STEEL CASTING ONE INCH THICK. C. SPECIMEN TUBE. D. SAND SPECIMEN. E. RUBBER TUBE. F. COLLECTING BOTTLE. G. TANK. H. OVERFLOW DAM.
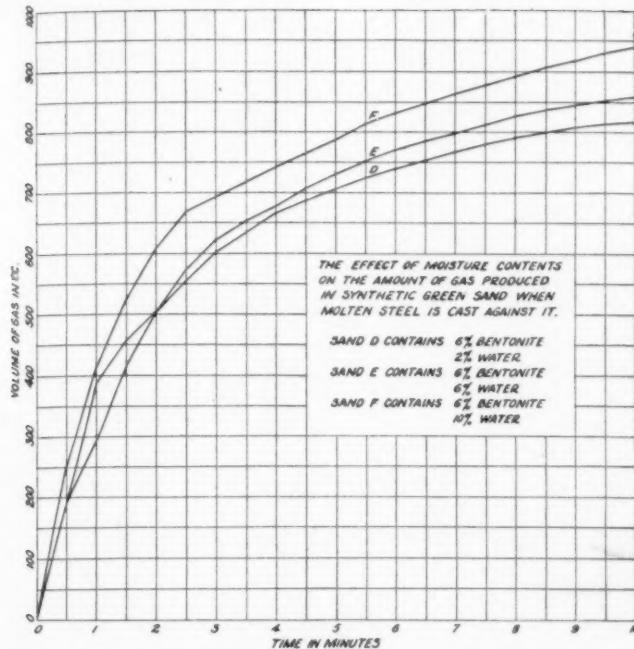
FIG. 24—EFFECT OF MOISTURE CONTENTS ON THE AMOUNT OF GAS PRODUCED IN SYNTHETIC GREEN SAND WHEN MOLTEN STEEL IS CAST AGAINST IT.

gas produced, three mixtures were made containing 4, 8 and 12 per cent bentonite and all were tempered to 5 per cent moisture. The results are plotted in Fig. 25 with the cumulative volumes of gas as a function of time. It may be seen that there is practically no increase in gas as the bentonite is increased.

76. Mixtures were then made to determine the effect of organic binders. A powdered lignin binder was used. The samples contained 4 per cent bentonite and 4 per cent water. Sample G contained no organic binder; sample H contained 1 per cent, and sample I contained 2 per cent of the organic binder (powdered "Bindex"). The graph (Fig. 26) shows that this small amount of binder causes a tremendous increase in the amount of gas produced. At 5 minutes, for instance, sample G, containing no organic binder, produced 751 cubic centimeters of gas, and sample I, containing 2 per cent of organic binder, produced 1314 cubic centimeters of gas. This is an increase of 563 cubic centimeters which is due entirely to the 2 per cent or 2.06 grams of organic binder.
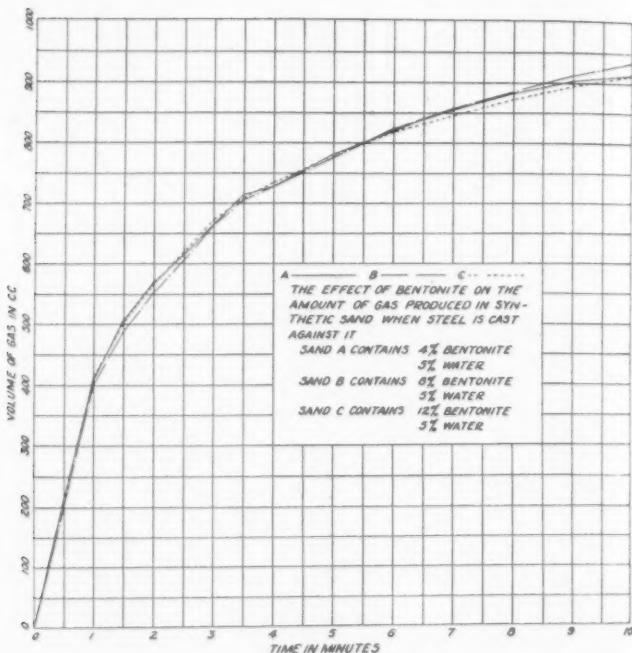
FIG. 25—EFFECT OF BENTONITE ON THE AMOUNT OF GAS PRODUCED IN SYNTHETIC SAND WHEN STEEL IS CAST AGAINST IT.

77. In a molding sand containing 4 per cent bentonite and 4 per cent water, it appears that in general on mold depths of 2 inches or more, approximately 14.5 cubic inches per minute of gas is generated per square inch of casting surface during the initial period of gas formation. A sand of 63.2 fineness can easily pass this amount of gas.

78. From a gas generation viewpoint the sand-bentonite-water mixture is much superior to mixes that include organic binders. Increasing water content increases the amount of gas generated, but nothing in proportion, however, to the increase that is obtained by the use of organic binder.

CONCLUSIONS

79. From a simple sand mix consisting of silica sand, bentonite and water, it is possible to prepare synthetic green sands, synthetic dry sands, and air dried sands with excellent properties. The synthetic dry sand may be prepared by merely oven drying the green sand mix.
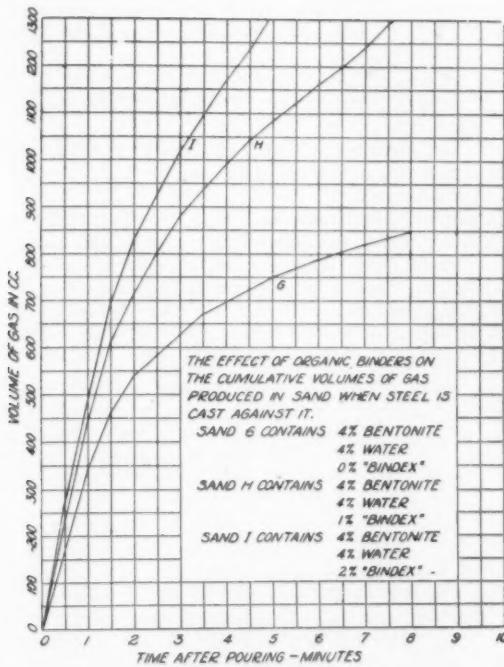
FIG. 26—EFFECT OF ORGANIC BINDERS ON THE CUMULATIVE VOLUMES OF GAS PRODUCED IN SAND WHEN STEEL IS CAST AGAINST IT.

80. Properties that were studied were green compression strength, green shear strength, green permeability, dry compression strength, dry permeability, flowability, deformation, and resilience. It was shown that excellent qualities and values in the above tests could be obtained with the simplified sand-bentonite-moisture mix.

81. The amount of gas evolution from synthetic bonded sand was also studied. Sand bonded with bentonite showed less gas evolution than sands bonded with organic binders.

Bibliography

1—Dietert, H. W. and Valtier, F.: "*Flowability of Molding Sand,*" TRANS. A.F.A., 1934, vol. 42, pp. 199-206.

2—Dietert, H. W. and Dietert, R. A.: "*Deformation and Resilience of Molding Sand,*" TRANS. A.F.A., 1936, vol. 44, pp. 139-156.

3—Nevin, C. M.: TRANS. A.F.A., 1924, vol. 32, part 2, pp. 168-181.

4—Dietert, H. W., Woodliff, E. E. and Schuch, J. A.: "*A Study of Steel Molding Sands,*" TRANS. A.F.A., 1938, vol. 46, pp. 257-279.

5—Hudson, F.: "*Some Properties of Mould and Core Materials at Elevated Temperatures,*" FOUNDRY TRADE JOURNAL, 1935, vol. 53, December 5, pp. 411-416.

6—Dietert, H. W.: "*Sand Testing and its Application in the Foundry,*" IRON AGE, 1936, vol. 138, July 30, pp. 24-27.

7—Carter, S. and Walker, A. W.: "*Molding Sand with Special Reference to Blind Scabs,*" FOUNDRY TRADE JOURNAL, 1938, May 26, pp. 423-428.

8—Hudson, R. F.: "*The Practical Value of Controlling the Properties of Moulding Sands at Elevated Temperatures,*" FOUNDRY TRADE JOURNAL, 1938, August 4.

9—Briggs, C. and Gezelius, R.: "*Studies in Solidification and Contraction in Steel Castings—III. The Rate of Skin Formation,*" TRANS. A.F.A., 1935, vol. 43, p. 274.

Appendix A

Correlated Abstract on Synthetic Sands, Bentonite and Clay Bonding Materials

Boswell, P. G. H. "*Ferruginous (Iron Oxide) and Other Bonds in Molding Sands.*" Trans. A.F.A., 1918, Vol. 27, pp. 298-307.

Excellent fundamental article. Analyses of British, Belgian, French and South African sands in bulk samples and in samples separated by size of particles, show that the coarse sizes contain up to 98 per cent silica, while the silica in the bulk sample runs from 77 to 90 per cent. In the clay portion the silica is between 42 and 46 per cent, with 20 to 25 per cent alumina and 10 to 13 per cent iron oxides. Alkalies (potash and soda) and alkaline earths (lime and magnesia) are low. This tends to produce refractoriness.

The silt sizes are unessential and present only in small amounts. Two fireclays are analyzed and it is shown that they are almost identical to the bonding clays. The only difference is that the natural clay contains more ferric oxide (12 per cent compared with 1.5 per cent for the fire clay). This explains and justifies the additions of clay to maintain strength and later the use of synthetic sand with clear sand grains and clay bond. At one time ferruginous materials were also added. This improves the strength but lowers the refractoriness.

One of the characteristics of good molding sands is their extraordinary power of taking up water without becoming wet. Some take up 14 per cent water. A good sand should not "go dead," that is, dehydrate rapidly. The author says iron oxide readily dehydrates (below 608°F.) and clay may be "porcellanized" by heat.

British Bunter sands (for iron and brass) have quartz grains with a very even coating of iron oxide (hematite or limonite) and have great strength for the amount of ferruginous material present.

The author believes that the difficulty in making good synthetic sands is in getting good bond distribution.

Staley, H. F. *"The Testing of Clays for Foundry Purposes."* **Trans.** A.F.A., 1920, pp. 465-476.

The author discusses the early methods used in testing. The clays were heated to 1200°C. If they burned hard they were classed as vitrifying; if they did not they were non-vitrifying. They were then heated to 1550°C. *Refractory* clays did not soften at this temperature and non-refractory clays did. The slaking test was used to determine plasticity. This was made by mixing the clay and potter's flint, 1 to 1 by weight, molding it in 1-inch cubes, drying in air at 110°C., then placing it on a ½-inch screen under water and measuring the time in minutes required for the sand to slake and settle through the wire.

Hansen, C. A. *"The Physical Properties of Molding Sand."* **Trans.** A.F.A., 1924, Vol. 32, Part 2, pp. 57-97.

Early sand test methods are discussed. Actual densities are determined by boiling in benzol to displace air and then weighing in benzol. Density of a silica sand was 2.65 and Albany sand, 2.67. Relations are developed between ramming, density, permeability and strength.

Green strength is believed due to the surface tension of water held between the grains of compacted sand. Dry sand is mobile because of the absence of liquid. A quick sand is one with the interstices completely filled with water and therefore has no water surface, no surface tension, and no green strength. The author thinks organic binders give sand some quality such as viscosity which can be felt with the hand but which tests do not measure. This viscosity retards sand flow during ramming and therefore causes greater density in the mold. Moldability is believed to be a combination of green strength and viscosity. When molders temper by feel they use a fairly high moisture. Additions of coarse sand won't open up a heap!

It is better to obtain dry strength by low clay contents and high moisture than visa versa. Dry sand molds need strength to withstand rough handling more than the action of metal. Organic binders will furnish this. They should be used sparingly (½ of 1 per cent for starches, sugars and gums). Too much will produce compressive strength higher than that of excellent concrete.

Alexander, J. *"Bentonite: Properties, Occurrence, Composition and Uses."* Industrial and Engineering Chemistry, Vol. 16, 1924, p. 1140.

Bentonite is described as a group or series of clay-like minerals characterized by an alkaline oxide and alkaline earth content of 5 to 10 per cent, fine grain size, high absorptive powers, usually very strong colloidal properties. The ultramicroscope shows a large percentage of particles of colloidal dimensions showing active Brownian movement.

When a volcano erupts it emits pulverized glassy lava which is carried off by the winds and deposited in strata. With it is hydrochloric and hydrofluoric acids, sulphur dioxide and possibly other corrosive gases. If the dust falls in a dry climate it remains as volcanic ash but if it falls in damp climate, lakes or sea, it may undergo rapid weathering and disintegration. This forms alumina and silica in partially hydrated form and possesses many of the properties of colloids. Bases are absorbed and in time the colloidal gel crystallizes into bentonite.

Bentonite crystals show distinct double refraction between crossed nicols which is regarded as proof of its crystalline form.

Nevin, C. M. *"The Relation of Water to the Bonding Strength and Permeability of Molding Sands."* Trans A.F.A., 1924, Vol. 32, Part 2, pp. 168-181. Good article.

Tests on several sands indicate that peaks in permeability and strength curves coincide in some cases and in some others the maximum strength requires less moisture than the maximum permeability, and still others the maximum permeability is produced with less water than the maximum strength. The latter condition seems to be connected with large amounts of silt, fines, and inert bond.

The author believes that in dry tempered sand the bond collects in the pore spaces; in medium tempered sand the water draws the bond around the sand grains and in wet tempered sands the "mobile bond" is weakened and allowed to flow back into the interstices.

Ross, C. S. and Shannon, E. V. *"The Minerals of Bentonite and Related Clays and their Physical Properties."* Journal of the American Ceramic Society, 1926, Vol. 9, February, pp. 77-96. Good article.

Analyses are made of several bentonites and from them the formula is calculated showing the variable water content of 4 to 7. The article shows that when the clay minerals are purified they are few in number and that each is a definite chemical compound of a simple type. Five minerals were found in the clays studied: (1) Montmorillonite (Mg, Ca) $O \cdot Al_2O_3 \cdot 5SiO_2 \cdot nH_2O$. (2) Beidellite, $Al_2O_3 \cdot SiO_2 \cdot nH_2O$. (3) Micaceous halloysite, $Al_2O_3 \cdot 2SiO_2 \cdot nH_2O$. (4) Halloysite, $Al_2O_3 \cdot 2SiO_2 \cdot nH_2O$. (5) Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$.

The alumina-silica ratio of 1-5 was found practically constant for pure montmorillonite and other ratios reported were believed to be due to detrical material in the sample. Bentonite usually contains montmorillonite but occasionally contains beidellite. Microphotographs indicate that bentonite was formed from volcanic glass and retains the original form of the glass. Bubbles, etc. may be seen through thin plates. The authors suggest that bentonite may not require special conditions for its formation and that it is merely the result of the instability of glass of a certain composition in the presence of water and the salts that are normally dissolved in it. Its wide distribution suggests that special conditions are unnecessary for its production.

The analysis of several samples shows an approximately constant amount of bivalent bases, principally magnesia with less lime and leads to the belief that they are a part of the mineral molecule which the authors express as—

$$R \ ''O \cdot R''' \ _2O_3 \cdot 5SiO_2 \cdot 5\text{-}7H_2O$$

or with 1 molecule of water basic and replaceable—

$$(H_2, \ Mg, \ Ca) \ O \cdot Al_2O_3 \cdot 5SiO_2 \cdot 5\text{-}7H_2O.$$

The alteration of the original glassy igneous material is usually so complete that they can only be determined by inference. They are believed to be Feldspar (orthoclase), biotite, and possibly trachytes, latites, rhyolites, nephelite bearing rocks and olivine basalt. Glasses high in silica are believed to be more stable and do not readily alter to bentonite. With a medium silica content, the glasses alter to montmorillonite with an alumina-silica ratio of 1-5 and, if the silica content is lower still, they alter to beidellite with an alumina-silica ratio of 1-3. Analyses and optical properties of 28 samples are given. The average index of refraction values are $\alpha = 1 \cdot 493$, β and $\gamma = 1.516$.

Scheiber, F. C. *"Synthetic Molding Sands in the Malleable Foundry."* Trans. A.F.A., 1927, Vol. 35, pp. 138-142.

The changes in foundry conditions from jobbing to production work and from skilled molders to untrained molders make natural sand undesirable. The men do not have the time or experience to temper and condition each batch to meet the variation in shipments. Synthetic sands and treated core sands are therefore substituted for the natural sands.

The treatment of core sands consists of burning at 500°F. in a barrel furnace to remove the binder, screening to remove scrap, and silt removal by air draft. Clay is then added as an emulsion bath to produce a synthetic sand. Glycerine is used to counteract the tendency to dry out.

Blakey, M. A. *"Testing Molding Sands for Durability."* Trans. A.F.A., 1928, Vol. 36, pp. 1-12.

Test molds were poured with iron to determine sand durability. Two thousand (2000) gram samples were made and were poured five times for the natural sands and ten times for the synthetic sands. Optimum moisture was determined before and after each test. Bond and permeability were plotted. The optimum moisture was determined for the new sand and after the final pour. The sand was then tempered to this moisture content and tested. The percentage of bond and permeability remaining after the final cast was used as a measure of the durability.

$$\text{Durability} = \frac{\text{final bond}}{\text{initial bond}} \times 100.$$

The appearance of the casting and the ease of shaking out, freedom from cuts and spalls, etc., gave additional valuable information in the selection of sands. Synthetic sands were found to be much more durable than natural sands.

DeWitt, C. C. and Brown, G. G. *"The Influence of Ferric Hydrogel in the Bond of Natural Molding Sands."* Trans. A.F.A., 1928, Vol. 36, pp. 247-276.

The authors show that (1) bond is increased by a stain of iron oxide on the silica grains, (2) that the stain is present in natural sands, and that (3) it can be produced artificially. They claim the method produces strengths which simple mixtures will not produce.

DeWitt, C. C. and Brown, G. G. *"The Cause of the Decrease in Bond Strength on Treating Molding Sands to 600°F."* Trans. A.F.A., 1928, Vol. 36, pp. 277-280.

Tests indicate that when sands are heated to 600°F. for three hours, it is not the silica grains or the ferruginous coating, but the clay itself which breaks down.

Kiley, T. F. *"Sand Control and Sand Conservation in a Gray Iron Jobbing Foundry."* Trans. A.F.A., 1928, pp. 359-376.

The author describes the change from uncontrolled natural sands to the use of bonding clays and sand control. Rebonding was instituted with large savings. This article illustrates the early practice and the simple methods used.

Davis, C. W. and Vacher, H. C. *"Bentonite: Its Properties, Mining, Preparation, and Utilization."* U. S. Bureau of Mines, Technical Paper 438, 1928. (Abstracted by O. A. Nelson, Chemical Abstracts, 1929, p. 1843.)

Pulverized bentonite is fine grained, light colored, dark or black. After firing, the color is white, buff or brown. Fracture may be conchoidal, platy or shale-like, or none at all. Its affinity for water is strong, it being able to absorb up to ten times its volume with consequent increase in bulk. It presumably represents a volcanic ash or lava altered to a hydrous silica alumina complex. Much of the substance of bentonite has not progressed beyond colloidal state as fully one-half of the particles in certain samples were of ultramicroscopic size. Other investigators state that the natural product contains no gel colloids but is composed of montmorillonite,

$$(Mg, Ca) \ O \cdot Al_2O_3 \cdot 5SiO_2 \cdot nH_2O \ (N = \text{approximately 8}).$$

and sometimes beidellite, $Al_2O_3 \cdot 3SiO_2 \cdot xH_2O$ (x = approximately 4). Colloidal properties are attributed to felted texture and micaceous structure in which the crystals have appreciable size in two dimensions but thickness of colloidal magnitude. Four types of bentonite were studied. The relative amount of swelling in water was found to be a rough method of classifying bentonite; swelling may be controlled by the addition of NaCl, other salts also affecting the swelling. Heat destroys the colloidal properties of the mineral. Regulated heat treatment differentiates bentonite in the same order as does swelling in water. This order was also followed in the absorption of dyes and the temporary osmotic pressures developed. Commercial bentonite was classified as (1) alkaline — bentonite containing easily replaceable alkaline bases and having original properties not permanently destroyed by H_2SO_4; (2) alkaline sub-bentonite — same as (1) except having original properties permanently destroyed by H_2SO_4; (3) alkaline earth bentonite — same as (1) except for containing alkaline earth instead of alkaline bases; (4) alkaline earth sub-bentonite — same as (2) except containing alkaline earth instead of alkaline bases. Three tests and a scheme for classifying bentonite are given.

O'Hara, C. C. *"Bentonite, Its Occurrence, Properties and Uses."* The Black Hills Engineer, January 1929, Vol. 17, pp. 39-48.

The location and geology of the deposits of bentonite in the Black Hills are discussed. The physical properties are described and the uses are listed.

Batty, G. *"The Most Potent Variable."* Trans. A.F.A., 1930, Vol. 38, pp. 309-321.

This paper is an excellent discussion of general sand practice. Among the points covered are fire clay, reclaiming, best grain shape, the effect of bond additions, bentonite, the blow hole defect and how it is caused.

Dierker, A. H. *"Essential Properties of Molding Sands."* Engineering Experiment Station News, Ohio State University, 1930, Vol. 1, March, pp. 6-7.

This is a very brief and elementary summary of the qualities a molding sand should possess. They are: (1) Plasticity. (2) Refractoriness. (3) Resistance to spalling. (4) Permeability. (5) Texture to produce desirable finish. (6) Breakdown to permit solid contraction of metal.

The various properties should be developed according to the metal and type of work produced. The controlling factors are: (1) Size and shape of grains. (2) Grain distribution. (3) Type of binder (clay, bentonite, organic binder). (4) Physical condition of binder (fineness, etc.). (5) Amount of binder. (6) Amount of water. (7) Manner of mixing.

Cole, H. J. *"A Comparison of Natural Bonded and Synthetic Molding Sands for the Steel Foundry."* Trans. A.F.A., 1931, Vol. 39, pp. 161-169.

Natural and synthetic sands were run simultaneously in a shop and notes kept on sands, preparation, results and cost. The synthetic sand cost a little more but could be reclaimed and used longer than the natural sand. The natural sand gave better finish and peeled better from the casting. It was a 92 fineness sand with 16.6 per cent clay. The synthetic was a 42 fineness sand with 12 per cent fire clay. The synthetic sand had a greater tendency to dry out on the floor and also dried easier in the oven.

Kerr, P. F. *"Bentonite from Ventura, California."* Economic Geology, 1931, March and April, pp. 153-168.

An excellent article describing the discovery, sampling, geology, and analysis of bentonite in the Ventura quadrangle in California. Optical and chemical tests were checked by X-ray diffraction patterns and the material compares almost exactly with material from Montmorillon, France.

Dunbeck, N. J. *"Clay and Sand Properties Play Important Part in Synthetic Sand Mixtures."* Foundry, 1931, Vol. 59, October 15, pp. 42-43.

The use of clay to maintain strength is discussed. The author believes that a sand with a fusion point of 3100°F. and a clay with a fusion point of 3000°F. are necessary for a refractory sand.

Knight, L. B. *"Some Observations on Preparation and Use of Synthetic Sand."* Trans. A.F.A., 1931, Vol. 39, pp. 718-727.

Reasons for synthetic sand: (1) Exhaustion of good natural sands. (2) High freight rates. (3) Cost of disposal of scrap sand. (4) Cost of handling new sand.

There is no basic difference between natural and synthetic sands. Both contain silica, clay and moisture. Synthetic sand contains less impurities (lime, iron oxide, etc.) and is more refractory. The author describes the change from natural to synthetic sands and the difficulties encountered.

Reichert, W. G. and Woolley, D. *"Factors Which Influence the Surface Quality of Gray Iron Castings."* Trans. A.F.A., 1931, Vol. 39, pp. 205-231.

Test castings were made varying grain fineness, moisture, mold hardness, sea coal, clay, method of ramming and pouring temperature one at a time to find the effect on the surface. According to this author grain size and moisture content are the main factors affecting surface quality. The metal used in the test was gray iron.

Dierker, A. H.   *"Grain Size and Bond Distribution in Synthetic Molding Sand."*   Trans. A.F.A., 1932, Vol. 40, pp. 230-238.

Mulled samples immersed in oil (index of refraction 1.55, similar to quartz) show bond but not grain. Thus the effect of mulling time can be shown. Small grain sizes take longer mulling.

Surface area is measured by four means and plotted. One method, considered to be the most accurate, was submerging the grains in a mirroring solution, measuring the silver deposit comparing it with the silver deposited on a quartz crystal of known area.

Briggs, C. W. and Gezelius, R. A.   *"European Synthetic Molding Sands."*   Journal of the American Society of Naval Engineers, 1933, Vol. 45, November, pp. 462-485.

Three synthetic sands, used successfully for steel castings in Europe were tested and compared with American sands. The materials were Chamotte, Industrial Extra, and cement bonded sand. For comparison duplicate tests were made on a Downer dry sand and a synthetic bentonite-silica green sand.

Chamotte is a highly aluminous clay, burned to a clinker and ground. It is then graded and material retained on the 12 and 20 mesh screens is mixed with raw clay and water. This granular structure gives permeabilities from 2000 to 2450; fifteen pounds per square inch at 5 per cent moisture and very low shear and tensile strengths. Dry compression is good but dry shear and tension are low. The sintering point is 1100°C. Tests indicate that this material transfers heat very rapidly away from the mold. This heat transfer is so fast that the sand ⅛" from the metal attained a temperature of 1880°F. In the cement bonded sand the temperature went up to 2470°F. showing a very low heat conductivity.

The German Industrial Extra consists of quartz and chalcedony grams with clay and a little pulverized carbon. It is sold ready to be tempered and used. The tests indicate that the permeability increases as the water increases. This is thought to be due to the balling action. These molds are washed with a prepared wash known as Edelschlichte. The cement sands were prepared with about 80 per cent silica grain, 10 per cent cement, and 10 per cent water. Cement sands are a little weak in the green state but their dry strength can be controlled by adjusting the cement and water content. The molds are washed and must be air dried.

Hudson, F.   *"Commercial Moulding Sand Control for the Modern Iron Founder."*   Foundry Trade Journal, 1933, Vol. 49, December 21, pp. 351-352, 360 and December 28, pp. 369-372.

This is a description of the installation of a sand handling unit and sand control in a British foundry. The unit was designed to accommodate a full conveyor system. It consisted of a return conveyor, rotary screen, elevator, four storage bins, and four mullers. The sand was distributed by tip trucks until a conveyor was installed.

Moisture was tested at the muller and the results were posted. Additions were made by a meter through nozzles around the top of the muller. A sand laboratory was used for tests.

Test figures were collected from American reports, the sand in use, and the results of foundries producing similar work. From these results the initial control values were set. A drop in dry strength was corrected

by a lignin binder. Coal dust was added to maintain the volume of gas produced from the sand above about 75 cubic feet per cubic foot of sand. High green strength was avoided to maintain flowability necessary for jolt machines.

Efficiency of rebonding agents:

Bentonite 100%
Colbond 50%
Dry ground fire clay.......................20 to 25%

A simplified sand was used for green and dry work. The dry sand was made from the green sand by adding 1 to 2 per cent of wood extract. This sand was also air dried in the foundry atmosphere for a few hours and poured with complete success.

Sheehan, J. J. *"Recent Developments in British Synthetic Moulding Sand Practice."* Foundry Trade Journal, 1934, Vol. 50, June 21 and 28, pp. 391-399 and 410-412, 415.

The author describes conditions in a foundry using natural sands, investigation of the sands, and the change to synthetic sands. About 95 per cent of the scrap loss was eliminated. Other investigations included comparison of smooth grains with grains roughened by the fumes of hydrofluoric acid bonded and tested for permeability and compression. The roughened grain was 10.3 per cent stronger. Smooth grains were compared with grains coated with ferric oxide. The coated grains were 18.5 per cent stronger. Sand was placed in a solution of ferric chloride; ammonium hydroxide was added to precipitate the ferric hydroxide and the sand was then dried and heated to drive off the ammonium chloride formed and burn on the ferric oxide. When synthetic sands were used entirely the permeability was raised due to the uniform grain size, alkalies were reduced, moisture was reduced and control of strength was possible. Colbond and bentonite were considered for bonding clays and Colbond chosen. Round etched or roughened grains of uniform size are described as the ideal sand. Methods of producing an iron oxide pellicle are discussed. Other refractory compounds may be burned on the sand grains such as manganese resinate, manganese silicate, and aluminum hydroxide. If the sand and bond adhere strongly the tendency to stick to the pattern is reduced.

Hudson, F. *"Some Properties of Mould and Core Materials at Elevated Temperatures."* Foundry Trade Journal, 1935, Vol. 53, December 5, pp. 411, 416.

This is an excellent article describing the technique and results obtained in testing sands for permeability, expansion and compression up to 1000°C. Sketches and photographs of equipment are included. Graphs show results. When checked this work should form a basis for further work. The author shows that the expansion of the air at high temperatures is responsible for the drop in permeability usually associated with high temperatures.

Expansion is mostly between 500 and 700°C. and amounts to as high as 0.15 inch per foot. Compression values go as high as 1260 pounds per square inch at 900°C. Above this temperature failure is plastic; below it is shear.

Casberg, C. H. and Schubert, C. E. *"An Investigation of the Durability of Molding Sands."* Bulletin No. 281 of the Illinois Engineering Experiment Station, April 1936, 52 pages.

Six kinds of sand were tested for durability by three methods: the mold test method, the oven test method, and the hydration and dehydration method. The procedure is described in detail and the results of the tests before and after each step are given in tables. The three methods are in general, but not close, agreement.

Examination of the sand shows that it does not wear out. The silica grains show very little change. The fineness and distribution numbers increase slightly. The principal change is in the clay which changes from a crystalline to an amorphous form. There is a very interesting section near the end of the paper on mineralogy and chemistry of the bonding substances. It contains very complete information on the behavior of clays in molding sand.

Montmorillonite

Up to 1022°F. montmorillonite absorbs water in reversible manner.
    At 1472°F. the lattice grouping is still intact.
    At 1832°F. the lattice grouping is destroyed.
    At 1112°F. anhydromontmorillonite is formed.
Between 932 and 1112°F. most of the water of crystallization is lost.

The ultimate products are mullite ($3Al_2O_3 \cdot 2SiO_2$) and a high temperature form of quartz (SiO_2).

Kaolinite

Absorbs water in a reversible manner up to 806°F. Reabsorption is very slow. Between 734 and 979°F., most of the water of crystallization is lost. Above 842°F. a mineralogical change takes place. At 1652°F. kaolinite changes to mullite and quartz which appears to be non-crystalline in structure.

Limonite ($2Fe_2O_3 \cdot 3H_2O$).

At 356°F. limonite loses water of hydration. Below this temperature it rehydrates easily, but above it, it won't rehydrate.

Base exchange capacity is the ability of the clay minerals to hold basic or acid ions on the surface of the materials. The base exchange capacities were obtained by leaching the materials with neutral ammonium acetate and washing out the excess of ammonium acetate with absolute methyl alcohol.

The ammonia absorbed by the material in replaceable form was determined by distillation into a standard acid solution after adding calcium carbonate, sodium sulphate and water. The excess of acid was then titrated with a standard sodium hydroxide solution and the base exchange capacity calculated in terms of milli-equivalents per 100 grams of substance.

The results of the investigation showed that bentonite molding sand has the longest life of any sand investigated. The strength decreased in accordance with the dehydration curve of montmorillonite, the principal clay mineral present.

Green strength appears to depend on the fineness of the clay, and dry strength on the physical or chemical properties of the binder. Calculations show that the dry strength can be predicted from the base-exchange capacity.

Dietert, H. W. *"Sand Testing and Its Application in the Foundry."* Iron Age, 1936, Vol. 138, July 30, pp. 24-27.

This is an elementary article describing the usual sand tests, what

the figures mean, and how to control them. (1) Moisture is the fastest changing variable. It should be tested frequently and water additions made accordingly. (2) Fineness and permeability should be balanced to give the smoothest casting possible with adequate venting. Maintaining a small distribution number increases the permeability for any given grain size. A sand can therefore be much finer for a given permeability if the distribution is small. A small distribution number is produced by adding material of the grain size desired, removing excessively coarse agglomerated grains and removing the fines, preferably by air suction. Permeability will then take care of itself. (3) Strength, green and dried, should be held at established values. If they vary too much, defects will occur. Green strength is produced by the amount and nature of the clay substance. It is best controlled by making daily additions of a suitable clay or Bentonite. Dry strength may be controlled by the clay additions or by the use of cereal binders, sea coal or molasses. (4) Expansion and contraction should be held to a minimum. The methods available are: (a) Reduce moisture. (b) Increase grain size. (c) Reduce ramming. (d) Reduce clay. (e) Increase combustible material. (5) Deformation control needs further research. (6) Sintering point may be raised by: (a) Increasing the grain size. (b) Increasing the mold hardness. (c) Reducing the clay content. (d) Reducing the fluxes. (7) Flowability may be increased by: (a) Decreasing green strength. (b) Decreasing the grain size. (c) Increasing the sea coal. (d) Tempering on the wet or dry side.

Dietert, H. W. and Dietert, R. A. *"Deformation and Resilience of Molding Sands."* Trans. A.F.A., 1936, Vol. 44, pp. 139-156.

This is the first article on deformation and resilience and describes the terms, etc.

Deformation is change in length of standard specimen at rupture load.

Resilience $=$ deformation $\times$ green compression $\times$ 1000.

Modulus of compression $=$ load divided by deformation.

A mass of information is presented showing the effect of various variables on deformation and resilience but additional study is needed to find their value. Deformation is affected more by moisture than any other variable tested.

Deformation increases: (1) rapidly as moisture increases. (2) as sand becomes finer. (3) when clay content is low or high. (4) as mold hardness increases. (5) as sea coal addition increases up to a maximum and then decreases. These values are said to give information about swelling under ferrostatic head, crushing (core prints, etc.) and resistance to shock and flask distortion.

Modulus of compression is increased by: (1) decreasing moisture content. (2) decreasing coarse material. (3) increasing clay content. (4) increasing mold hardness.

Sand resilience is increased by: (1) increasing moisture content. (2) increasing fine material. (3) increasing clay content. (4) increasing mold hardness. (5) increasing sea coal.

Grim, R. E. and others. *"The Constitution of Bond Clays and Its Influence on Bonding Properties."* Trans. A.F.A., 1936 Vol. 44, pp. 211-223.

Excellent article. Informative and precise. All clays are composed of a small group of clay minerals as follows:

Kaolinite .... $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
Anauxite .... $Al_2O_3 \cdot 3SiO_2 \cdot 2H_2O$
Halloysite .... $Al_2O_3 \cdot 2SiO_2 \cdot xH_2O$
Beidellite .... $Al_2O_3 \cdot 3SiO_2 \cdot xH_2O$
Nontronite .... $Fe_2O_3 \cdot 3SiO_2 \cdot xH_2O$
Montmorillonite .... $Al_2O_3 \cdot 4SiO_2 \cdot 4\text{-}7H_2O$
Sericite-like mineral .... $K_2O \cdot 3MO \cdot 6R_2O_3 \cdot 18SiO_2 \cdot 5\text{-}10H_2O$

These minerals have a micaceous crystalline habit to varying degrees.

Analytical Procedure (p. 213. See also Bray, R. H. and others.) *"Application of Clay Mineral Technique to Illinois Clay and Shale."* Bull. Geol. Soc. of Am. 46, pp. 1909-1926 (1935).

(1) Remove easily soluble material and exchangeable bases to permit suspension of colloidal fraction. (2) Dispersion and sedimentation to remove particles over 1 micron. (3) Fractionation by supercentrifuge. (4) Optical study by petrographic microscope of bulk sample and fractions. (5) X-ray diffraction photography of colloid fractions. (6) Chemical analysis and base exchange capacity determinations of bulk sample and all fractions.

Fractions

Residue	R	$+1.0$ micron diam.
Coarse colloid frac.	C	1 to 0.1 micron diam.
Fine colloid frac.	F	0.1 to 0.06 micron diam.
Superfine	S	-0.06 micron diam.

Base exchange made by leaching with ammonium acetate followed by neutral alcohol wash. The replaceable ammonia was determined by distillation.

Test-comp. and perm. A.F.A. standards:

3000 g. standard sand ⎱
145 g. clay (4.6%) ⎰   Temper 165.6 g. H_2O to 5%

Mix 7 minutes in a Simpson Laboratory Mixer and temper 24 hours.

High base exchange indicates high green strength but an approximate value is all it will give because of other variables. For instance, base exchange will vary with particle size and bonding strength will vary with the nature of the exchangeable bases present.

It is possible that the addition of acids or alkalies may be used to control the nature of the exchangeable bases. (Sodium, calcium, and hydrogen.)

Heat alters clays and the nature of the alteration is important to understand molding sand durability.

Montmorillonite is dehydrated gradually up to 1022°F. (550°C.). Above this temperature crystallographic changes begin. Below this temperature the sand will retemper. Beidellite is similar.

Kaolinite loses little water below 752°F. (400°C.). Between 752°F. (400°C.) and 950°F. (510°C.) almost all moisture is lost. After heating to 392°F. (200°C.) it rehydrates very slowly and after heating to 806°F. (430°C.), it rehydrates very slightly. Sericite-like mineral is similar.

Limonitic material (red and yellow hydrated iron oxides) loses practically all moisture below 392°F. (200°C.) and rehydrates very slightly.

Decomposition products of clay are various forms of Al_2O_3, SiO_2, mullite, glass, etc., depending on the original material and the temperature. These products are not flake shaped and will not cause plasticity or green strength in sand.

The mineral composition rather than the ultimate chemical analysis gives the nature of the clay.

"Synthetic Moulding Sands." Engineering, 1937, Vol. 143, Feb. 26, 1937, p. 248.

Due to a large supply of fairly good molding sands and the conservatism of British foundrymen, little interest was shown in synthetic sands until the last year or two.

The author believes a good synthetic sand should contain 90 to 95 per cent pure silica, 3 to 5 per cent bentonite, suitable amounts of organic binder, and moisture. Too much bentonite is bad practice. The amount used, however, is usually so small that it has very little effect in lowering the fusion point of the sand. The most important sand qualities are strength (green and dry) permeability, moisture and refractoriness or fusion point. Flowability, grain size and grain shape are also important. Most of these characteristics are interdependent and often show wide variations in natural sands.

Clay is the principal factor governing sand characteristics. If the clay content is too high, fusion point and permeability decrease; if too low, green and dry strength are lacking.

A good bentonite is the best clay for synthetic sands. Sources of supply are discussed. There is bentonite at Cumberland (England) and dependable supplies are being developed in Canada from the Pembina Hills. Bentonite gives the greatest strength of any dry binder with a minimum percentage of clay. 3 to 4 per cent is sufficient for new sands and 1 per cent or less for heap sands. These sands lend themselves to rapid, economical mechanized production and are easily controlled.

It is sometimes desirable to add 3 to 10 per cent silt in the form of silica flour to prevent erosion and improve finish. It is possible to use lower moisture contents than with other clays and the range of workable moisture contents is wider. 1.25 per cent to 3 per cent may be used without serious loss of green strength. Silt formation is reduced to a minimum and dispersion in milling is easy, due probably to the fine size and flat shape of the bentonite particles .

The discrepancy between British and American practice is a difficulty standing in the way of progress which should be cleared up.

Carter, S. and Walker, A. W. *"Moulding Sand with Special Reference to Blind Scabs."* Foundry Trade Journal, May 26, 1938, pp. 423-428.

The authors describe the institution of sand control in a British jobbing foundry. Sand handling and mixing machinery was installed and it was noted that the more efficient mixing developed latent bond in the sand so that the plant ran for 12 months with only occasional very small new sand additions. This resulted in marked improvement in finish. When rebonding became necessary, a strong natural sand was used for some time, in amounts just large enough to maintain the strength. Recently this was replaced with colloidal clay. For dry sands the same mixture is used except that the moisture is raised from 5½ to 7½ per cent. Coal dust was eliminated and 0.3 per cent wood pulp was added to provide extra dry strength. Loam is made from the same mixture except that the moisture is much higher.

The storage bins over the sand mills were open at the top until it was found that so much silt and fine material was blowing away that the casting finish was affected. Covering the bins remedied the defect. Fines and silt also appeared to stick to the larger grains as compound grains and therefore a "silt problem" was considered improbable.

The bentonite increased the dry strength without having any harmful effects on the other properties. It was also found necessary to mix the sand a little wetter to counteract the tendency to dry out. Additions of ½ of 1 per cent of bentonite were used at first, but these were soon reduced to ⅛ of 1 per cent.

Blind scabs or buckles are discussed and the authors believe that this defect is not due to sand expansion but to a dried skin of sand pulling away from the green sand. They did not occur in properly dried dry sand molds but were frequent in green sand where the level of the metal remained still for a short time before the mold was completely filled.

Walker, T. R. *"Some Factors in Sand Testing."* Foundry Trade Journal, June 9, 1938, pp. 455, 456, and June 16, 1938, pp. 483, 484.

These are excellent and practical articles. The A.F.A. and B.C.I.R.A. test cylinders and methods of compressing the sand are discussed. The British cylinder has a 1 square inch cross section and is believed to be more uniform. It has a volume of 37 cc and is rammed to some predetermined relative density by ramming first on one end and then the other. (A relative density of 1.6 requires 1.6 x 37 or 59.4 grams of tempered sand. This is placed in the 1.128 inch diameter tube and rammed to a length of 2.256 inches. The relative density of the A.F.A. specimen can be obtained by dividing the weight of sand necessary for a 2 inch high cylinder by 103 cc. If 164.8 grams are used, 164.8 divided by 103 gives a rammed density of 1.6.)

The compression test is the most popular at the moment and it is used exclusively in these tests. Loading should be axial. A yield point is often noted. If water is added progressively the green strength rises rapidly to a maximum and then falls slowly. Increased ramming gives increased strength. The influence of time is shown to be very important. Green strength should be determined immediately after the cylinders are made. If they are allowed to stand they dry out and the strength rises rapidly at first and then more slowly, finally reaching an almost constant value varying slightly with the temperature and humidity. The original moisture content to which the sand is tempered affects the original green strengths and the strength attained on air drying. The factors affecting dry strength are, for the first time, very well treated. The time a specimen is left standing before baking it is shown to have no effect on the dry strength. The dry strength depends on the water content in the green state. An increase in water gives an increase in dry strength. Drying can take place at any temperature if the vapor pressure is low. Specimens dried 5½ hours in vacuum, 10 days in a desiccator, 2 hours in an oven at 105°C., and 1 hour in an oven at 200°C., had dry strengths almost identical. If the specimen is too strongly heated, some of the water of hydration in the clay is driven off permanently and the dry strength is lowered. For some clays the minimum temperature necessary to cause this change is below 200°C. This temperature should not be exceeded in the drying oven.

Difference in the conditions after drying has a great effect on the dry strength. The specimens are strongest when crushed hot. Consistent but somewhat lower results are obtained by allowing the speci-

mens to cool in a desiccator and crushing at room temperature. As the cylinders stand in air they cool to some critical temperature and then begin to absorb moisture. This moisture absorption continues and the strength drops until an almost constant value is reached. This shows the need for keeping baked molds warm until they are poured.

The author expresses the need for an international standard set of sieves. Without them it is very difficult to compare the work of different investigators and practically impossible for different investigators to duplicate results. Even when using the same sieves, the results vary with the method or machine used and the time of sieving. The use of fine sieves is believed to be very inaccurate and elutriation is advocated instead. If sand testing is to progress, it is necessary that one investigator should be able to accurately reproduce the work of another in the simplest tests, such as compressive strength and grading. When this has been made possible, there will be a sound foundation for progress.

DISCUSSION

Presiding: JOHN HOWE HALL, Philadelphia, Pa.

F. A. MELMOTH[1] *(Written discussion):* With increased knowledge of steelmaking, and the development of a technique suited to the production of steel for castings made in sand molds, I suppose it would be true to say that the major problems of the steel foundry today are concerned with mold-making materials and their methods of use. The production of an average mold to receive steel is not by any means scientific. With carefully produced sand, of definite chemical and physical characteristics, variations of method in use can produce results widely divergent. The approach to the problem, therefore, cannot be dogmatic in type. The type of work being produced, which involves all sorts of practical factors related to sand behavior, can quite possibly make a sand which is successful in one plant a failure in another. Compromise on sand characteristics is frequent, owing to practical exigencies, which causes one to approach the matter of sand mixture simplification with caution and due respect.

In spite of the holding of these opinions, which are based on many years of interest in mold materials, during which, on frequent occasions, I have been proved wrong by hard practical facts, when scientific, logical discussion probably would have approved my opinion, I welcome sincerely such papers as the present one. Any effort to simplify foundry procedure should be given respectful attention.

The portion of this paper dealing with bentonite bonded sand, and detailing variations of behavior with differing proportions of mix and water content, forms a valuable basis for the consideration of sand mixtures. I doubt seriously, however, if we have progressed sufficiently to say that the behavior of a sand in test is an invariable indicator of what will happen to it when it forms part of a mold into which steel has to be cast. I believe profoundly in sand control, but tend definitely to the

---

[1] Vice-President & Works Manager, Detroit Steel Castings Co., Detroit, Mich.

view that its use and value is mainly to insure regularity of a condition which has been proved by actual practice to be correct for the purpose intended.

The range of effects upon sands, and their resulting behavior, is extremely wide in a jobbing foundry, and so far it is not by any means simple to arrive at a true idea of their behavior in practical conditions by their characteristics in laboratory tests. These latter, as I have said, represent an excellent guide and means of control, but can be an extremely unreliable master.

The use of cereal binders represents a good case in point. They add to expense, and therefore none of us wants to continue their use if they are not of direct and proved benefit. They unquestionably add to the amount of gas to be dealt with during pouring, a further proof that founders would welcome conditions eliminating their use. Yet, in how many really well-managed steel foundries are these cereal binders in constant use? We are using small amounts to give green support to oil sand cores, of a type otherwise very troublesome. Are we to assume that the coremakers are completely incapable of detecting any improvement resulting from its use?

Cereal binders are often associated with bentonite in green sand facing for light castings, particularly so where immediate pouring after molding is impracticable. Dirt spots, broken-down edges, and so on were present to a high degree prior to their use for this purpose, and it has been assumed that the slowing down of the surface drying-out in these highly permeable sands, and the tendency to air-dry firmly, as a result of the addition, was a factor in preventing this very bad trouble. It has also been assumed that they add dry strength, and that cleanliness of a green sand casting is often affected greatly by the dry strength exhibited by the facing sand. Are we to assume that these opinions are entire fallacies on the basis of laboratory-exhibited characteristics? There is always the possibility, of course, that these long established practices are based upon a fallacy, but in most cases they have grown out of absolute practical necessities, and have proved their points to the extent of becoming widely accepted.

Increasing water content in straight bentonite sands was, of course, tried at once, but was not found beneficial. High permeability predicates quick drying out of the surface, and in such sands this produces a pliable, loose condition, tending to break down during pouring. Much finer sand for facing also presents the possibility of overcoming the trouble, and is much more helpful than higher moisture. It has to be remembered, however, that such fine facing has an accumulative closing-up effect on backing sand, and local porosity may soon show itself as a result. At this point it is worth issuing a warning that turning over to the ultra-fine sand for facing may appear to be perfectly satisfactory for a period of time, but vigilance is absolutely necessary where the backing sand is concerned, or the last stage of this trouble can be worse than the first.

The paper is very useful in its present form, but I believe that the authors may have to modify some of their conclusions if faced by the hard facts of foundry production of a widely varying range of castings. I believe that there are far too many sand mixtures used in the steel founding industry, but I am not yet able to believe that for a number of years the master minds of the steel founding industry have had before them such a simple means of completely eliminating this undesirable condition and yet have failed to take advantage of it. The opinions of some of the more practically trained members should be of really high value in the discussion of this paper.

P. E. MCKINNEY[2] *(Written discussion)*: Although many foundrymen have already made considerable use of synthetic bonded sand mixtures, this paper performs a valuable function in organizing our knowledge of the subject. The data, which the authors have accumulated, may not prove infallible when applied directly to full scale operations, but should permit a much clearer understanding of whatever results are obtained. Having the information firmly in mind, the adjustment of synthetic mixes in actual practice should become less haphazard than heretofore.

It is possible that the authors, in their desire to simplify the subject, have proceeded too far in that direction. Until it has been proven that a foundry, especially a jobbing foundry with a highly diversified product, can obtain uniformly satisfactory castings by using one general all-purpose sand, I will be inclined to question whether all of the complex mixtures now in vogue can be promptly eliminated.

Concerning the complete renouncing of all cereal binders, there are probably a few applications where they might be retained. One of these, in which unusual mold hardness is desired, was mentioned by the authors in paragraph 56. In one of our foundries we use corn flour, as a green bond, in making oil sand cores. In this connection, a bentonite mixture is used in preference to cereal mixtures at another plant. Brackish Chesapeake Bay water furnishes the moisture and, of course, some salt. The latter appears to benefit mold properties to a noticeable extent.

It is to be hoped, that a number of foundries will put to practice much of the information which the authors have developed. If such experimental work were carefully planned, reported and combined, the relationship of these laboratory results to foundry operations could be rather exactly defined, thus enhancing the practical value of this paper. Notwithstanding the critical nature of these comments, I consider that the authors have done a piece of work which has been well performed and should have a very desirable influence on general foundry practice.

A. H. DIERKER[3] *(Written discussion)*: The objects of this investigation, as stated by the authors, is commendable. However, a careful reading of the paper causes one to feel that they have wandered somewhat from these objectives. We cannot escape the conclusion that the

real objectives of the investigation were: First, to demonstrate that bentonite is the only bond necessary in green as well as dry sand molding. Second, that organic binders are unnecessary and detrimental to sand quality.

We do not feel that the results of the quite limited laboratory experiments conducted by the authors justify the conclusions drawn.

In Table 1 the authors give the screen analysis of four sands of different A.F.A. fineness numbers, purported to have been used in the investigation. However, the data presented cover tests on one sand only, i.e. fineness number 63. This is unfortunate, for the authors show in paragraph 30 how a difference in grain size distribution can effect the properties of the sand. It is also unfortunate that they did not use for their experiments, a sand that is more generally used by steel foundries as a base for synthetic mixtures.

In paragraph 64 the authors state that the sintering point of the sand was lowered 125°F. by the introduction of cereal binders. This is quite surprising. Ceramic investigators for years have been using organic binders in making up test specimens of non-plastic materials for fusion point determinations, and feel that the binder does not affect the fusion point. There seems to be good reasons for questioning the value of the usual laboratory test for the fusion or sintering point of molding sand, since the conditions of the test are so different from the conditions inside the mold. The writer has previously shown* that the surface of molten steel in a sand mold is oxidized and that the oxide reacts with the surface of the mold forming a skin of iron silicate of rather low melting point. The formation of this iron silicate skin has a material influence on the importance of the normal fusion or sintering point of the sand.

It is not quite clear, from the authors' description of their gas collecting apparatus, (Fig. 23) just how they prevented steam (a substantial part of the gas formed in a mold) from condensing in the water in the collecting bottle. It would seem important to differentiate between steam and gases from organic binders. The former is highly oxidizing, the latter would have a tendency to be reducing.

Throughout the paper the authors appear to base their conclusions on the assumption that there is a direct relationship between the results of laboratory tests and service conditions in commercial steel foundries. They, however, fail to give any evidence in support of such assumptions. Experience to date would indicate that the standard tests are of more value for control purposes than as absolute measures of the suitability of a given sand mixture for commercial foundry use.

Over a period of years, hundreds of thousands of tons of steel castings have been poured, in green and dry sand molds, containing organic binders, by foundries that enjoy a reputation for quality work. In view

* Dierker, A. H., *"Reclaiming Steel Foundry Sands,"* Trans. A.I.M.E., Iron & Steel Division, 1930.

of this fact it would seem unwise to be hasty in concluding that organic binders have no place in steel foundry facing sands.

C. P. RANDALL[4] *(Written discussion):* This is indeed a very splendid paper on synthetic sands. It will do much to unveil some of the mysteries or at least some of the disputed points concerning characteristics of synthetic sands. It will provide also an incentive for the wider use of synthetic sands because of the apparent case of predetermining physical qualities of the molding sand heap. Moreover, the paper will beyond all doubt strengthen the belief that no foundry, intent to make good castings cheaper, can afford to be without sand control. To those of us who have participated in sand research, control and testing, an appreciation of the tremendous amount of effort and diligent application of thought, which the authors have set forth in the preparation of this paper, is quite apparent. Both Mr. Briggs and Mr. Morey deserve much credit and praise for their splendid work.

To discuss this paper at length in this brief space is, of course, impossible. One point, however, which should be remembered is the fact that this work, as stated by the authors, is the preparation and study of a simple sand with clay and water. In all tests virgin sand was used and the results, therefore, should be so construed. It is obvious, for example, that when a sand is once used, it may not produce the same characteristics in successive preparations. In other words, a synthetic sand heap, as well as a natural sand heap, will undergo definite changes over a period of time.

The authors have included in their investigation two properties which I believe have a very definite bearing on the production of good castings. For a great many years permeability, strength and moisture have been the guides to better castings. Not always have we been able to eliminate defects by judicious adjustments in these three properties. Deformation and resilience, to which I refer, are properties which lend themselves to a more thorough diagnosis of sand ills.

There is one point which I would like to have the authors clarify. In contrasting a good and poor sand distribution as in Table 3, two sands were selected having the same grain fineness. The one had 100 per cent material on the 100 mesh sieve and the other distributed over several sieves. Obviously to prove the point in question, two quite dissimilar sands were selected. Disregarding the fact that such a sand does not exist, except by synthesis, would this not be an acceptable sand in the production of very small castings for example? The permeability is only 17 points lower, which is not in disfavor of small castings. Then again, the green compression strength is 1.14 lb. per sq. in. greater in the case of the poorly distributed sand. This strength, of course, can be lowered at will by a reduction of clay percentage, thereby increasing the permeability or voids, decreasing the strength and increasing the collapsibility to prevent hot tears. While it is generally conceded that

---

[4] Hunt-Spiller Manufacturing Corp., Boston, Mass.

uniform grain size is conducive to better castings, is it not true that a
sand whose component grains are spread over, perhaps three or four
sieves, will yield an entirely satisfactory casting from the standpoint of
appearance and freedom of defects? In other words, a sand does not
necessarily have to be retained on one, two or maybe three sieves, to
qualify as an acceptable sand for certain classes of work.

It will be understood that the above discourse does not in any sense
of the word condemn the intention of the authors, but merely emphasizes
the fact that the sand whose grains are concentrated on one or two
sieves is not always the best sand to use.

T. West[5] *(Written discussion):* This paper was read with keen
interest as most of the steel foundries have now turned to making syn-
thetic bonded sands with only bentonite as a bonding material in addi-
tion to water. The authors state that one foundry has six molding sands,
which in turn are prepared into fifteen different mixes. In the writer's
opinion this is troublesome. Fifteen mixes require more correct hand-
ling and mixing than would three to five sand mixes. If a molder
received the wrong mix for a certain job and the job was completed
before the mistake was noticed, the probabilities are the castings would
turn out all right. So why have fifteen different sand mixes just to
satisfy one's desire to have another facing just a little different from
the rest of the mixes. I certainly agree with the authors in the state-
ment that the number of sand mixes must, not could, be reduced and
the mixes simplified.

Naturally, using different materials and equipment, our experiences
all vary. However, this paper has been presented from facts and there-
fore, we have the necessary basis on which to discuss results and
improvements.

The sand used in this paper was a New Jersey silica sand. The
question comes to the writer as to whether there is any difference as to
grain distribution—round or sharp grains and impurities of silica sands
not washed—in the sands around the country. If there is, which there
must be, what might we look for in foundries located in different
districts?

Another question that comes to my mind—What form of sand mix-
ing equipment is used by the various foundries? It has been said that
different types of mullers mill sand differently and that sand mixes
have to be changed from muller to muller. Have the authors any definite
facts proving or disproving of this? What is their experience? What
difference exists between two similar sands, one three minutes in the
muller and the other five minutes in the muller?

The authors put their samples in a container to temper for 24 hours.
Foundry conditions are just the opposite as the facing sand goes into
the mold almost immediatley. What advantages are there in allowing
sand to remain confined or enclosed?

---

[5] West Steel Casting Company, Cleveland, O.

The authors state that if flowability can be increased, casting will be improved and ramming decreased. Sometimes a jolting machine does not seem to jolt the sand hard enough and instead of looking into the flowability of sand, the machine is inspected closely and repaired, so to speak. Another point nowadays is the lesser number of jolts necessary to ram a mold, the more molds than can be turned out, and the better the working day.

In Fig. 6, the weight of specimen curve does not agree with the tabulated data in Table 2. Is this an error or should the curve at the lower moisture content be a straight line?

The authors state (Paragraph 25) that the maximum resilience, 112, occurs at 3.0 per cent water, which is very close to the moisture used in the average green sand. The average green sand moisture in our shop is around 3.8 to 4 per cent. If the moisture content falls below 3.8 per cent, the molders complain about the sand, bad lifts, inability to patch. etc. The writer would like a discussion of the moisture contents as used by others.

One fact shows up in the A.F.A. fineness standard. From the screen tests of two identical A.F.A. fineness numbers, entirely different sands are found. For uniformity's sake, the A.F.A. standard should be so rated that different screen analyses cannot be secured from the same fineness number.

Have the authors anything to substantiate their mulling time of five minutes (Paragraph 30)? Has the fineness or coarseness of the sand anything to do with the change in mulling time? If so, to what degree?

The authors make a statement (Paragraph 31) that uniform sand has a much smoother surface and both were about equal in regard to rubbing off. We use bottom pour ladles in our foundry and, as a result, the sand has to stand a lot of rubbing off. Just recently some castings showed up in the cleaning room with peculiar defects on the cope side. Everything available was tracked down to no avail until one day it was noticed on a cleaned casting that the casting in front of the gate was just a little rough. A ram-up core was placed on the pattern in front of the gate and the casting was poured. The cleaned casting did not have a sign of a defect as shown on the former casting. This goes to show how important rubbing off can be.

Another question that comes to the writer's mind is: Will bentonite ever build up in backing sand so as to make the additions of new, bondless sand necessary? Fig. 9 shows that bentonite closes the sand to some extent as the moisture is increased. There is a decrease of permeability in the optimum moisture content of the bentonite mixes as the bentonite content increases, which shows that the backing sand has to be watched or the bentonite will close it up if the percentage of bentonite increases greatly.

In Table 4, the authors have listed dry permeabilities of bentonite mixes with the different percentages of moisture. The writer does not question the figures in the dry permeability column, but is at a loss to understand why the dry permeability is so variable when only moisture is added.

The writer would like to ask if there is any percentage of moisture left in a dry sand mold under actual working conditions? The mold, if allowed to stand any length of time, will certainly pick up atmospheric moisture and thus have some small percentage of moisture. However, if the mold is poured immediately after coming out of the dry oven, this pick up of moisture is entirely eliminated.

On air dried sands, is it possible to close the mold and let it stand overnight and have the same air drying results as a mold which has been left open over night? What reasoning and facts are behind the statement that air dried castings are easier cleaned?

From Fig. 20, it is possible to have the same mold hardness, 85 for example, in one hour of air drying time with two different percentages of moisture, 3 and 6 per cent. The writer would like some explanation of this.

The writer would like to know if the authors had sintering points for a 1 per cent dextrine, 3 per cent bentonite, A.F.A. silica sand No. 63? Also, the sintering point for 1 per cent ceres, 3 per cent bentonite and using the above mentioned sand.

For years we have used facing sands containing ceres and dextrine and have yet to find the time when the sand, as the authors say, becomes sticky from the use of cereal binders. Perhaps we do not use as high a percentage as that which the authors have in mind to make a facing sand sticky. We have used 1 per cent dextrine and 2 per cent ceres in different mixes with no tackiness appearing. However, in the last eighteen months we have eliminated almost entirely the cereal binders and are using a straight bentonite for bonding material. At the present time we are using old sand for the bench and squeezer work, adding 1½ lb. of bentonite to 408 lb. of old sand. However, when our old sand runs out, we add a part of new sand to each batch, maintaining a total weight of 408 lb., and the bentonite mixture will jump to approximately 3 lb. The permeability of the old sand mix is from 150-160, green bond is from 5.0 to 6.0, and the moisture runs from 3.8 to 4.0 per cent.

Fig. 23 shows the sand specimen tested for gas, produced in a steel container. The container, being steel, certainly would conduct heat away from the molten metal quicker than sand. Would not this have a tendency to make the result a little lower, than if the steel container were eliminated and a whole mold capped?

In closing the writer wishes to compliment the authors on this splendid paper, as it brings to light facts about sand and its mixes which before have always been accepted by hearsay evidence.

C. H. LORIG[6] *(Written discussion)*: This paper is an extremely valuable contribution on the physical properties of the bentonite bonded steel molding sands. It shows that the moisture, the bentonite contents, and the grain size distribution of the sand, are all important in regards to the physical properties of these sand mixtures. Such information is both helpful and desirable to the steel foundry industry, as it provides the industry with quantitative data on a phase of foundry practice upon which there is surprisingly little published.

It does not necessarily follow that the physical properties of sand mixtures are an absolute measure of the behavior of the mixtures in molds, though the relationship between properties as they are determined and the behavior of the sands in molds, is quite good at times. Thus, while the bentonite bonded sands may appear highly desirable for dry and skin dried molds from the standpoint of physical properties, it is questionable whether any foundryman with a desire to produce castings of good finish would advocate the use of sand mixtures bonded only with bentonite. Air dried, skin dried, and oven dried molds of bentonite-sand mixtures have very poor surface bond. Sharp edges, as well as the surface of the mold after such drying, rub off easily and offer little resistance to metal erosion. In dry sand molds, the dry bonds such as cereal binders, pitch, resin, etc., have a definite function of offering greater resistance to erosion.

Normally the dry bonds have little or no effect on green sand properties. However, for green mold surfaces exposed for some time to radiant heat from hot steel, i.e., before the steel is actually in contact with the mold surface, dry bonds may be employed to advantage in the green sand mixture.

The authors described a very ingenious test for the amount of gas produced from various sand mixtures. Before one can concede the superiority of the sand-bentonite-water mixture over mixes that include organic binders on the basis of gas generated, it should be realized that steam generated from the moisture, and the gases given off by the organic binders behave differently in the mold. The steam generated in the sand near the casting surface, condenses in the cool sand farther back and if the sand does not have sufficient permeability, or if the moisture content of the sand is excessive, this condensed steam may form an impermeable barrier a short distance from the casting through which it is impossible to vent. Gases from organic binders, on the other hand while their amounts may be far in excess of the steam formed from green sand mixtures, will not condense nor will they interfere with venting of the mold to the same extent as will the moisture. Gas forming products in molding sands, therefore, may not be harmful so long as the sand remains permeable during the solidification of the casting. In many applications it is definitely advantageous to gain dry strength in mold sand mixtures with dry bonds rather than with high moisture contents and bentonite.

⁶ Battelle Memorial Institute, Columbus, O.

It would have been interesting had the authors supplemented the physical testing of the sand mixtures, with information on the behavior of the mixtures in molds. Not only would the value of the paper been greatly enhanced, we would then have a direct comparison of the various sand mixtures in regards to their qualifications under foundry conditions.

D. L. PARKER[7] *(Written discussion)*: This paper, like many others Mr. Briggs has been associated with, gives to the foundryman basic fundamental data of a nature that is needed by the industry. The title might well be changed to "Synthetic Bonded Molding Sands," as the data are directly applicable to iron and non-ferrous practice. There are a number of iron foundries I know of, located in the New England district, which are experimenting with synthetic sand to whom this paper will be a distinct help. I refer particularly to the combined graph shown in Fig. 18. This can be put to practical use.

The authors' findings on the effect of moisture in the green state on the dry compressive strength of synthetic sand, shown in Fig. 16, is of importance in helping to solve shake-out problems in both iron and steel, more so the former, where in many instances continuous pouring on a conveyor system is common practice and the sand must leave the flask and casting readily in order to take advantage of mechanical shake-out.

In paragraph 23, the authors refer to the weight of sand necessary to make a specimen exactly 2-in. high. Was this the exact height of the specimen used in all the tests, and if so how was it accomplished?

The findings in regard to the effect of cereal binders on properties is interesting, particularly the loss of strength with increasing quantities of cereal. The results obtained by the authors are identical with a series made at Cornell University in conjunction with the high temperature tests, being conducted under the direction of sub-committee 6b7, of the A.F.A. Foundry Sand Research committee. These tests showed a very definite increase in green and dry compression starting with a 4 per cent bentonite and 4 per cent cereal mixture by weight and going to a straight 4 per cent bentonite mix by gradually reducing the amount of cereal; green compression went from 5.6 to 8.1 lb.; with the dry compression from 2.9 to 22.3 lb.

It has been my privilege to visit the Norfolk Navy Yard where mixtures of the type described by the authors are being used in daily production, and I would like to ask them what other steel foundries are using similar mixtures? I know of an iron foundry making textile machinery castings that has had very successful results over at least a year and a half using a sand mixture of silica sand, bentonite and water with the sand heaps cut over daily with a sand cutter.

H. L. DAASCH[8] *(Written discussion)*: The work of the author is a worthy contribution to the study of molding sands. The furtherance of

[7] General Electric Co., West Lynn, Mass.

[8] Associate Professor of Mechanical Engineering, Iowa State College, Ames, Iowa.

simple and reliable synthetic molding sands is a step in the direction of positive, yet scientific, control. With the thought of possibly establishing more firmly the basis of the authors' work, the writer wishes to discuss and question certain items.

Paragraph 11 indicates that the sands were mulled but no statement of the amount of mulling water is given. If we presume all temper water was added during mulling, a variable ratio of mulling water to bentonite is evident. On the other hand, paragraph 19 indicates adjustment of temper water from 1 to 10 per cent. This implies less than 1 per cent water for mulling of the 2 to 10 per cent bentonites; possibly again a situation of variable mulling water to bentonite percentages.

This seems an important point to the writer. A series of tests, quite similar to those reported by the authors, were made in the writer's laboratories. However, the ration of mulling water to bentonite was varied over a wide range. These mulled products were oven dried at 230°F. and then tempered with temper water approximating optimum for green strength. Results are indicated in our Fig. 27 where green strength is plotted as a function of the ratio of mulling water to clay.

It is quite evident that the ratio of water to bentonite is important in establishing the strength of the resulting molding sand. The writer
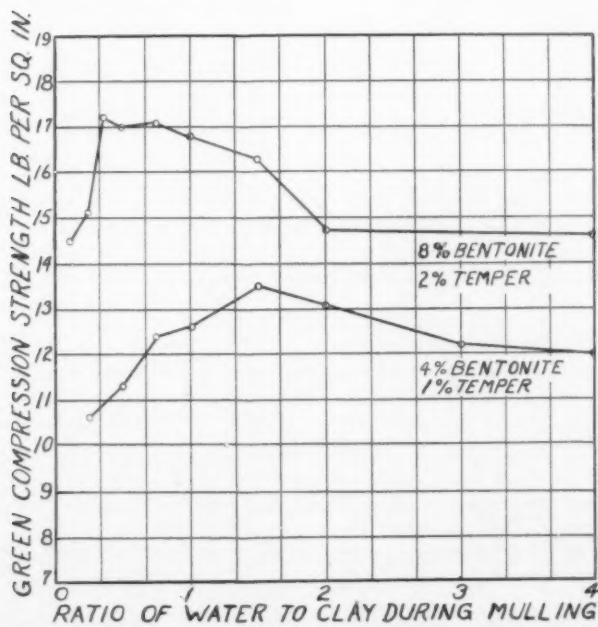
FIG. 27—EFFECT OF VARYING WATER TO CLAY RATIOS ON GREEN COMPRESSION STRENGTH.

recognizes full well other variables in mulling practice; in no way does he intend to make comparisons between specific values shown by his Fig. 27 with the values shown by the writers in their paper. Rather, he wishes to call attention to a mulling water condition not specifically outlined and possibly neglected by the authors.

Another item of experimental procedure should be noted. The writer has replotted strength and permeability as shown in Table 2. Figs. 28 and 29 herewith compare with Figs. 8 and 9 of the paper. The first point, a purely academic one, which the writer wishes to make is that experimental data should be shown on graphs. This procedure seems vital to full appreciation of the work being reported. Logically, the interpretation of experimental data is individualistic. Yet the records of the transactions of such organizations as the A.F.A. are records of efforts to establish fundamental and scientific truths. The human element toward all such attempts must be recognized, and the writer's suggestion is merely in accord with a desire to establish the records of greater value for convenient future study.

The second point that the writer would make in comparing the graphs noted in the above paragraph, is a result of many hundreds of similar molding sand physical property tests conducted during his own investigations. The writer has been impressed with the frequent (and generally unexplained) variations to simple laws he might be tempted to conceive. Molding sand (even a simple mixture as advocated by the authors) is apparently not simple in the number of variables involved in determining its characteristics.

Fig. 8, for example, indicates a situation of regularity not at all experienced by the writer in similar studies. Fig. 8 probably shows facts not verified by the data nor possibly intended to be concluded by
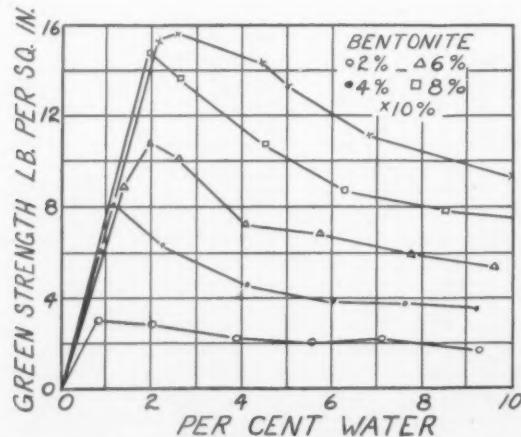
FIG. 28—EFFECT OF WATER AND BENTONITE ON THE COMPRESSIVE STRENGTH OF SYNTHETIC SAND.
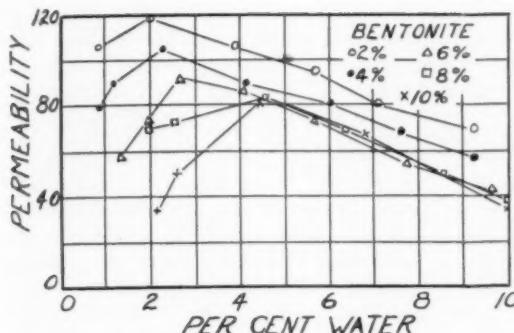
FIG. 29—PERMEABILITY OF SYNTHETIC SAND AS EFFECTED BY BENTONITE AND MOISTURE
CONTENTS.

the authors. Similar statements may be made for other families of
curves shown in the paper. In other words, Fig. 8 becomes an idealized
chart and might be so specified. Better still, the original data should be
shown by plotting. Whether curves of Fig. 8 or our Fig. 28 would
fit would then easily be understood, and shown, as human interpretation
and easily discussed upon that basis. The writer would, obviously, favor
facts as illustrated in his Figs. 28 and 29.

The writer would also prefer not to skip over the question of per-
meability and gas generation. For example, can it not be theorized that
gas generated, as by a facing mixture, may be an aid to surface finish?
A balance between quantity of gas generated, permeability of the mold
and the rate of casting skin solidification seems more reasonable in estab-
lishing casting surface quality, than the straight-forward desire for a
sand that "will generate a minimum of gas."

The paper is unquestionably well planned and the formal con-
clusions most modestly presented. The thesis of securing variable com-
binations of properties is highly practical. The work and data outlined
merit the time and attention required by an intensive study by all
concerned with molding sands.

T. S. QUINN[9]: In reading this paper and translating it into terms
of steel casting green sand manufacture, I think that the results as
shown do not translate themselves into terms of good steel castings. I
can confirm the remarks of Mr. Melmoth from my own experience in
trying to work with bentonite and develop the use of cereal binders.
I can also report from the tests we have made both before this paper
was written, and since, that the results are not comparable in the
product which we undertook to make; viz, castings weighing from one
to five thousand lb. When using only bentonite as a binder, the castings
were not satisfactory in surface appearance and cleanliness. Of course,
I have no way of knowing whether that statement can be confirmed by

[9] Treasurer, Lebanon Steel Foundry, Lebanon, Pa.

others making electric castings. Therefore, we do feel until more is known about substitutes for objectionable gas-forming binders, such as cereal binders, we will have to continue to use them in our foundry in the production of our product.

I wish this paper had dwelt more with castings based on the result of these experiments whereas the paper is very general on that subject. I also wish that the authors' remarks had included reference to the recovery of these sands. Many of the foundries located close to sand banks are not very worried about sand costs, but we who are not so favorably situated, with sand costs of four or five dollars a ton, have to think of sand recovery and it would have been interesting if this paper had touched on that problem.

C. E. SIMS[10]: My attention was drawn to the first paragraph of the paper where it states that in one case it was known that there were six steel molding sands in a shop, which in turn were prepared into fifteen different mixes. I know of one foundry which checked up and found that they were using thirty-four different mixes. There are not that many different mixes required in a jobbing shop and on reappraisal they discovered they could reduce the mixes to a considerably fewer number.

The authors have undoubtedly reached their goal in one respect at least. They have provided an excellent source of information on silica sand-bentonite-water mixes so far as the physical properties are concerned.

I was impressed with paragraph 57 about organic binders, where it says, "The value of these organic binders is somewhat doubtful . . . ," and later in the paragraph, "It is difficult to prove this point, as the writers know of no test that correlates mold hardness with its ability to resist erosion or spalling by the action of the molten metal." By the same token, the information relative to these bentonite sands would have been of vastly greater value if they had been checked with the action of steel on the sand. After all, the important thing is how the sand is going to stand up under the action of steel and what kind of casting will be obtained.

Another point is the method of testing for gases evolved. The method described undoubtedly determined the amount of permanent gases formed. It, however, ignores the matter of water vapor, and water vapor, in my opinion, is by far the most harmful gas in the formation of porosity in steels. I was going to say it was the only harmful gas. The graph of Fig. 24 shows that by varying the water content in bentonite mixes one does not vary the amount of gas formed. The principal gas there would be vapor, which is not measured.

H. D. PHILLIPS[11]: The value of this work done by the authors is appreciated. We have repeatedly tried out bentonite bonded sands, and

---

[10] Battelle Memorial Institute, Columbus, O.
[11] Dodge Steel Co., Philadelphia, Pa.

we have for years recognized the advantages that would result to our castings were it possible for us to use a bentonite-water-silica sand mix. We would get better pattern detail. We would lessen our molding time on molding machines. We have proven that by time studies. These advantages, however, we have always found to be offset by the fact that in the cleaning room we would find quite a bit more trouble in the way of eroded sand showing up on the cope surfaces.

I am quite interested in this matter of gas formation. I would not say, as some may, that most of our trouble is in the metal, or in the mold, or anything of that type, but the making of good steel castings requires that we understand and control both. Now, I do not know, from my own experience, of any foundry that goes quite as high as one or two per cent cereal content by weight. Less than half of one per cent is enough to allow us to properly finish our molds.

As to gas evolution and the type of gas and its effect on pin-hole porosity, a number of years ago we tried a series of cereal bonded and bentonite bonded sands making test molds and subsequently sectioned the castings. There was very little or no difference in the pin-hole formation that could be laid to the type of bond used. I think I can concur very readily in Mr. Sims' opinion, that moisture is the most important factor in pin-hole porosity.

This paper is of considerable value. It is along the line of work of which we are very much in need in the casting industry. It is a basis for further work and it is to be hoped that it is considered in that light, and if carried on to a finish, it is going to react to the advantage of all of us.

D. C. ZUEGE[12]: I think there is no question but what satisfactory castings can be made with and by a bentonite-sand-water mix under ideal conditions. It has, however, been our experience that the addition of cereal binders to the bentonite-sand mix gives us a sand which, under operating conditions where a box of sand may stand around for a while, seems to be more workable.

There is one other point that I believe has not been stressed very much this afternoon, and that is the subject of collapsibility of the sand. That property is especially important in the manufacture of long thin castings, where the relationship of casting section to the mold resistance is relatively small. If we have a sand that is too strong we know we get cracks. It is true that certain things can be done with our bentonite-sand mixture to give us a greater degree of collapsibility with some mixtures than others. On the other hand, there is no question about the fact that bentonite, as our present knowledge goes, gives us a greater high temperature strength than most of the cereal binders and so, it has been our experience that in certain cases, the use of these cereals is necessary to secure collapsibility.

[12] Sivyer Steel Casting Co., Milwaukee, Wis.

I agree with Henry Phillips that this work has been an invaluable contribution to our knowledge of sand, because it certainly has been a very extensive study of the property of bentonite-sand mixes.

MR. BRIGGS: We are not going to attempt to answer the oral discussion. I know you realize it is not necessary for us to do so. We thank everyone who contributed to it as their discussion has contributed much to the paper.

It has been generally supposed by the discussors of the paper that the experimental work was not tried out under commercial conditions. It has, as some of you here this afternoon know, for you have seen such a sand in production. We have said very little on this point because our remarks would be merely reflecting our opinions, and we believe opinions do not usually carry much weight. We will, however, further state that the sand-bentonite-water mix is being used in three foundries with very good success for miscellaneous castings production. Other than this we have nothing further to add.

The discussors are right when they say the paper is not the answer to all synthetic sand problems. It is realized that there are many and various sands in use in foundries today just as there are many types of work going on throughout the shops. We do not expect that the answer to our problems is the answer to theirs. We present these data merely to show how a systematic study of properties may be obtained. We have cut down the variables to only three. Perhaps some of you will wish to go on from there. If we have stimulated enough thought on the subject to have all of you give a little attention to it, that is all that we desire.

There is one further point, please do not misunderstand us in believing that we have taken a stand in opposing the use of cereal binders in foundry sands or cores. We have not. We merely stated that under certain conditions in green sand work we have found that they were not necessary.

C. W. BRIGGS AND R. E. MOREY *(Authors' Closure to Written Discussion)*: The authors appreciate the interest of all who contributed to the discussion and wish to thank them for their comments and suggestions.

We do not mean to condemn the use of any kind of binder. In some cases they may have their advantages and, when they are proven to produce better results, they definitely should be used. It was the intention of the authors to provide a basic mixture which any steel founder could modify to suit his individual conditions.

In reply to Mr. Melmoth's observation, on the extent to which laboratory tests are a true criteria of mold conditions, we can only say that in our small experimental foundry, as well as in some large foundries, this mixture has produced excellent castings. The tests used in

this study were, in most cases, standard or tentative standard tests of the American Foundrymen's Association. It is recognized that they may be inadequate in certain respects, but they are the best we have, and until others are developed we must get along with them.

Mr. Melmoth implied that we had suggested that cereal binders are no value in core mixtures. If the reader will review the text he will notice that no reference is made to cores or core mixtures. We are well aware and tests have shown that in reference to cores the use of cereal binders are commendable. We should also like to call to Mr. Melmoth's attention that a great many tests of a very systematic character are involved in the study to determine the proper relations for commercial use. The information presented in this paper has contributed in adopting mixtures for the production of steel castings.

In regard to modifications of the basic mixture, it is believed that the use of somewhat finer sands for the full mold, more angular sands, and a good cereal binder in amounts not over one-half of one per cent may be beneficial.

The comment of Mr. McKinney that there are applications, such as where high mold hardness is desired, where cereal might well be used, is pertinent. A large amount of work remains to be done on sand, and if the commercial steel founder will use the base sand described with carefully controlled variations to suit his individual requirements, it is believed some valuable information will surely result.

Mr. Dierker, in his first paragraph, undertakes to state the objects of the investigation by saying the authors attempt to demonstrate that bentonite is the only bond necessary in green as well as dry sand molding, and that organic binders are unnecessary and detrimental to sand quality. He states further that " . . . a careful reading of the paper causes one to feel that they have wandered somewhat from these objectives." It is difficult to give Mr. Dierker credit for the "careful reading of the paper" which he claims because the objects of the investigation are stated clearly in paragraph 7. They are:

(1) To prepare a simplified synthetic green sand.

(2) To prepare a simplified synthetic dry sand.

(3) To study the properties of green sands when various cereal type binders were incorporated in the mix.

Mr. Dierker further states that four sands were purported to have been used in the investigation and that the data shows only one. He is referred to paragraphs 29 and 33 and to Fig. 15 in which data on the other three sands are presented. In the same paragraph, Mr. Dierker states, "It is also unfortunate that they did not use for their experiments a sand that is more generally used by steel foundries as a base for synthetic mixtures." The sand used is actually one of the most popular sizes of a large Eastern producer, and it is used extensively as a base

for synthetic sand by many steel foundries. We believe that this points to the fact that Mr. Dierker is not very well acquainted with steel foundry production methods.

In regard to the gas collection results, it should be pointed out that in nearly every case the steam generated condensed in the test specimen and never reached the collecting bottle. This was the result desired because the authors were interested in the permanent mold gases and not in the steam which is an unavoidable evil in green sands.

We note Mr. Dierker's opinions that the conclusions which were drawn from the experimental data are not justified. We are not greatly distressed thereby since Mr. Dierker presents no data to justify such a statement. Therefore, we believe that his statement more aptly applies to him than to us.

We are indeed sorry if Mr. Dierker does not like the A.F.A. sintering test, that is slightly beyond the scope of our paper. We, however, do not appreciate his insinuation that we have falsified our sintering tests. We would suggest that he contact the Bureau of Standards as to this point and obtain their experience in this regard.

Our reason for not presenting service conditions may be found in our reply to Mr. Lorig.

Virgin materials, as Mr. Randall states, were used in the investigation and repeated use of the sand will produce changes in it. We have used the method of making a strength and moisture test on our heap sand and plotting these values on Fig. 8, as described in paragraph 27. The location of this point on the graph tells us how much of the bentonite in the heap is still effective. From this we calculate the amount of additional bentonite necessary to bring the heap up to an established strength value of bentonite content. An occasional fineness test will show if there is any accumulation of fines, or other change in the sand. This method has worked well in our experimental foundry.

Both the sands in the distribution study would probably produce good castings. While the sand with uniform round grains has often been called the ideal sand, it is entirely possible that a slightly angular sand spread over several sieves may make better molds. Such a sand will have higher strength, but lower permeability and lower flowability. A more extended series of tests on such sands would be very interesting. The curves showing strength as a function of water content would undoubtedly show some interesting variations in location of maxima, slope, etc.

In reply to Mr. Tom West may we suggest that the various sands throughout the country will undoubtedly show some variation depending on grain shape, distribution, natural clay, if any, and possibly other factors.

Most foundries using synthetic sand, mix it with mullers. Mullers will vary in their effect depending on the speed, adjustment, weight of

charge, mechanical condition, and time of mulling. In our mullers, however, we find very little difference between 3 and 5 min. mulling time. The test batches were mixed 1 min. dry; water was then added and mixing continued for five min. in a Simpson 18-in. laboratory muller. The 5 min. mulling time was used because it is suggested in paragraph 78 of "Testing and Grading Foundry Sands and Clays." The next paragraph states that the sand should be stored 24 hr. in an air-tight container to secure maximum temper. This is, of course, just opposite to foundry conditions where the sand is usually used a short time after mixing. The authors investigated this point and found that, for the sands used, the 24 hr. tempering period has little if any advantage. In natural sands it may give the clay a chance to rehydrate.

In Fig. 6, there was probably a small experimental error in one of the weighings. These readings were the weights in grams necessary to produce specimens 2-in. high and the height was measured by the center mark on the top of the sand rammer. It is difficult to read this closely. The weight was drawn as a curve, however, because the related curves (Fig. 10) indicate that this is true.

Several factors may affect the amount of water necessary in a green sand. If the sand contains any silt or natural clay, it will probably require more moisture than a straight bentonite mix with a uniform washed silica sand.

In the distribution study, two sands have the same fineness number. A distribution number is needed to differentiate between them. It is hoped that the American Foundrymen's Association will decide on a simple method of expressing distribution in the near future.

It is not believed that bentonite will ever build up in the backing sand so as to make additional bondless sand necessary. The opposite is more apt to be true. We make small bentonite additions to our heap from time to time. So far we have been unable to detect any trouble from fines building up in the backing sand, although we make no effort to remove them.

The writers cannot attempt to explain the variation in dry permeability with change in water content. Dry strength varies enormously with change in water content, so it is assumed that there is some difference in the way the clay is distributed or in the way the grains are packed.

In hot, thoroughly baked molds, most of the free water is driven off. They will pick up moisture again as soon as they cool, especially if the air is humid. Air dried molds are never actually dry. They are partially dry at the surface and green underneath. The drying effect is seldom over an inch or two in depth. This green backing sand makes air dried molds easier to shake out than hard, baked molds.

It is possible to produce the same hardness in the same sand with two different water contents. The drier mix hardens quickly but does

not become very hard. The wetter mix hardens more slowly but eventually becomes harder. There will, therefore, be a point where the hardness curves will intersect.

We have no sintering data on the mixes mentioned.

The test used for the amount of gas produced, has several disadvantages. The steel tube may chill the steel. It does not measure steam and the joint between the tube and the steel may leak. Except with high moisture contents, most of the steam seemed to condense in the specimen and did not even reach the tube. Only the permanent gases were measured. The subject of gas evolution, the production of steam and its condensation and the transfer of heat through the mold, should provide material for some very interesting research. A better method for gas measurements would be welcomed. Capping a whole mold is not the answer because too many new variables are introduced. The expansion of the air would appear to produce large volumes of gas.

In reply to Mr. Lorig, may we point out that the information presented in this paper is based on data and not on opinion. The learned discussion by Mr. Lorig is devoid of data and while presented in a factional manner is after all only Mr. Lorig's personal opinion.

We believe that it goes without saying that properties, as shown by the sand test specimen, do not necessarily represent the properties of the mold. This point is well understood by all steel foundry operating executives. Just as in the same manner a tensile test specimen from a coupon does not necessarily represent the properties of the casting. However, it is not necessary to explain this fact every time that a coupon is tested. Air dried, skin dried and oven dried molds of all sand-bentonite-water mixtures do not have poor surface bond. It is easy to see that Mr. Lorig has not investigated this subject completely or he would not have made this statement. The fineness of the sand, the character of the sand, and the amount of water used are very important points in this regard. In numerous cases metal has been dropped 3 to 4 ft. down the sides of large molds without erosion greater than that which would be found in any other type of sand mold given a similar treatment.

Also may we add that regardless of whether Mr. Lorig questions it or not, there happens to be several foundrymen who are using mixtures similar to those outlined in the paper and producing castings with excellent finish.

In dry sands, the organic binders increase the compression strength materially, but I know of no test information which shows that they increase the resistance to erosion. Also if they do increase resistance, that does not prove that a bentonite-water mix does not have sufficient resistance. We all know that the high mold strengths that may be obtained through the use of organic binders, are not necessary from the standpoint of exceeding the ferro-static pressure of molten steel. The added strength of these molds merely acts to resist the contraction of the castings.

Mr. Lorig states: "Normally the dry bonds have little or no effect on green sand properties." This point we proved. He further goes on to state: "However, for green mold surfaces exposed for some time to radiant heat from hot steel, i.e. before the steel is actually in contact with the mold surface, dry bonds may be employed to advantage in the green sand mixture." Mr Lorig presents no data to substantiate this statement. We wonder if he has ever taken temperature gradient studies in the sand at the mold surface, and back slightly from the mold surface in the mold, under the conditions of which he speaks. Also we wonder if he is familiar with the properties of these sands as the temperature of the sand increases. Information on these points would be welcomed by the committee on high temperature sand testing.

We are well aware of the method in which gas is generated in a mold. We also stated that because of the smaller amount of gas a sand of a lower permeability could be used. Our conclusions as to superiority was based on a "gas generation viewpoint," which we very carefully stated in the text. If Mr. Lorig believes that gas forming products in molding sands are not harmful, he must convince numerous steel foundrymen other than ourselves of this fact.

We call upon Mr. Lorig to prepare a paper in which he sets forth the definite advantages to be gained by the use of dry bonds in attaining dry strength in preference to the sand-bentonite-water mixtures. We should like to point out that we did not compare the two types of sands. Our purpose was to present information on a simplified sand mix that would fill the conditions of all types of molding methods. This we believe we have done. We have not claimed a superiority of the sand-bentonite-water mixtures over any special sand mixture used for a special product. We do not present the faintest suggestion that an organization with a dry sand practice should scrap their sand mixture and go to a sand-bentonite-water mixture. The paper was prepared for miscellaneous casting shops with diversified sands in order to simplify their sand problem. Green, air dried and dried sand molds have been prepared with the sand-bentonite-water mixtures and excellent results have been obtained. Besides that we claim nothing. We are not interested in selling sand, bentonite or water.

We did not supplement the physical testing of the sand mixtures with information on the behavior of the mixture in the molds, since anything so presented would be merely opinions. We believe that if anyone is sufficiently interested in the test data they will investigate their qualifications under foundry conditions. We have and found them satisfactory. Nothing more than this would be given greater weight.

The authors appreciate Mr. Parker's remarks on the use of synthetic sand for iron and non-ferrous metals. They suggested this at the 1938 convention, but the idea was not very well received at that time.

The specimen height was controlled by weighing the sand before ramming the specimen. If the specimen was within 1/16-in. of the

correct height it was used and a correction made on the next specimen. Usually by the third trial the weight necessary to produce the correct height was arrived at. Since from six to ten specimens were used, most of them were exactly two in. high and all of them were within 1/16-in. It was found necessary to make all the specimens in the same tube due to wear on the inside changing the volume slightly.

It is gratifying to know that our findings in regard to the loss of strength produced by some organic binders have been corroborated.

If Mr. Daasch will examine table 2 he will find the bentonite and water contents in the first two columns. From these he can figure the water to bentonite ratios. New material was used for each mix and it was, for all practical purposes, dry. Except for traces of moisture in the sand and bentonite, all water was added in the muller.

It is, of course, the option of any worker to plot experimental data as broken lines or smooth average curves. If few tests are made, it is, in the author's belief, best to use broken lines. If, however, a great many tests indicate that some experimental curve has a characteristic shape, it is believed that a smooth curve should be used. It is felt that while one or two points may be slightly off the curve, due to experimental error, they have little weight compared with many tests which indicate the characteristic shape.

It is perhaps unfortunate that the experimental points were not traced in preparing the curves for reproduction, because the original curves of Fig. 8, for instance, show that 21 points out of 32 are on the curves, and that 5 more are within 0.2 lb. per sq. in. of the curves. Five of the remaining six points are within 0.5 lb. per sq. in., or 0.25 per cent water, of the curves. This leaves one point (2.56 per cent water, 15.64 lb. per sq. in.) which was assumed to be in error. The point (2.16 per cent water, 15.22 lb. per sq. in.) is the result of a check run made to determine the accuracy of the previous point. It indicates that the error was probably one of moisture content.

We believe that the showing of smooth curves to illustrate trends are easier to follow, and are, therefore, of greater value than broken line curves. The chances of anyone obtaining a carload of sand exactly similar to that which we have used is very slight and since sand distribution, grain characteristics and fineness number are important in the values to be derived, the actual points are not of practical interest. The trends are the all important thing and, therefore, are guides to other workers studying this subject.

Copper, Aluminum, Silicon Alloys
for
Addition To Cast Iron

V. H. Schnee* and T. E. Barlow,* Columbus, Ohio

Abstract

The purpose of this investigation was to determine the effects of ladle additions of a complex alloy, containing a strengthening element in combination with the well known "deoxidizing" elements, on the properties of cast iron. A series of copper base alloys, containing different amounts of aluminum, manganese, and silicon was selected as most suitable for investigation. After preliminary tests, an alloy containing 6 per cent aluminum, 12 per cent silicon and 80 per cent copper was selected as most suitable for use with medium carbon electric furnace cast irons.

It was determined that additions of one per cent of this alloy were sufficient to effect decided improvements in the mechanical properties of the cast irons tested. It has been shown that ladle additions of one per cent of the copper aluminum silicon alloy are more effective in raising the tensile strength and toughness as measured by resilience, than additions of 0.5 per cent silicon added as ferrosilicon. A comparison of the effects of additions of the copper, aluminum, silicon alloys with additions of copper alone indicate that the alloy improves the propties of cast iron more than straight copper additions. It is emphasized that the reported test results have been obtained on electric furnace irons. Tests on cupola irons made under commercial conditions are planned. It is believed that alloys containing less aluminum and silicon will be equally effective when used with the higher carbon irons.

Introduction

1. In these days of high test cast irons, the control of structure in the iron is becoming increasingly important. The lower carbons and higher temperatures ordinarily used to produce the

---

high test irons aggravate the tendency of cast iron to form ab-
normal structures on freezing, particularly in thin sections with
relatively high cooling rates. These structures, known variously as
primary ferrite, snow-balls, dendritic, under-cooled or simply as
modified structures, have a profound effect on the properties of cast
iron. They are commonly associated with lower strength and tough-
ness, increased sensitivity toward chill and decreased wear resistance.

2.   The differences between a normal graphite structure and
a typical modified structure may be illustrated by a comparison
of the irons shown in Fig. 1. Iron *A*, shown in Fig. 1 contained
2.96 per cent carbon, 2.12 per cent silicon and had a tensile
strength of 43,000 lb. per sq. in. Iron *B* contained 3.08 per cent
carbon, 2.16 per cent silicon and had a tensile strength of 30,000
lb. per sq. in. These irons, which are quite similar in chemical
composition, are markedly different in properties. The improve-
ment in properties that can be obtained by proper control of the
structure of an iron is frequently greater than can be obtained
by even large changes in composition.

3.   This is equally true of alloy cast irons because the max-
imum effect of alloy additions can be realized only when the base
iron has the best possible structure. The addition of expensive
alloys to a highly modified iron is neither good foundry practice
nor sound economics.

4.   Ladle additions of ferrosilicon have, according to Mac-
Pherran[1]†, been in use since 1895. Coyle and Houston[2] discussed
them and MacPherran[3] gave details on a final silicomanganese
addition. Smalley's work with silicocalcium is well known[4], while
Lemoine[5] has utilized silicotitanium or silicochromium. More re-
cent investigations by Crosby and Herzig[6], Comstock[7], and Mc-
Elwee[8] have shown that the tendency of cast iron to form modified
structures is greatly reduced by the addition of small amounts of
ferrosilicon, ferrotitanium, aluminum or zirconium to the iron in
the ladle, just before pouring. The late addition of these and
other elements, either alone or in combination, results in a more
nearly normal structure with consequent improvement in the prop-
erties of the irons so treated.

5.   A further improvement in properties should be realized
if the beneficial effects of a true alloying element could be obtained
in addition to the effects of the elements added primarily to control

† Superior numbers refer to bibliography at end of paper.
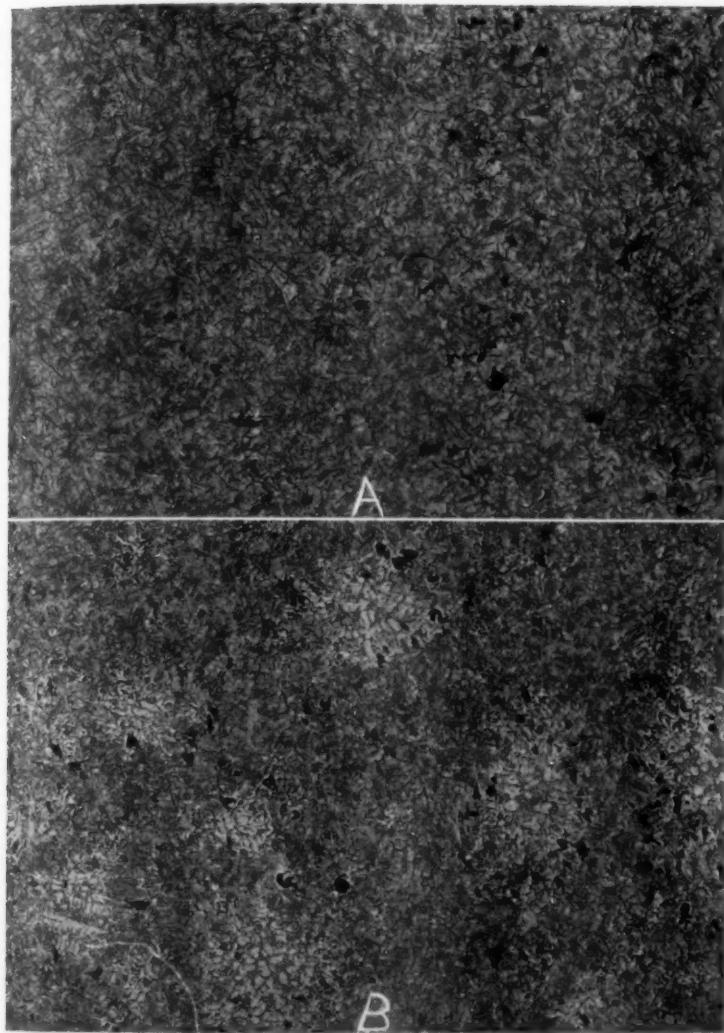
Fig. 1—Showing Difference Between a Normal Graphite Structure and a Typical Modified Structure. X40.

Iron A		Iron B	
Carbon, per cent	2.96	Carbon, per cent	3.08
Silicon, per cent	2.12	Silicon, per cent	2.16
Tensile Strength, lb. per sq. in.	43,000	Tensile Strength, lb. per sq. in.	30,000

the structure of the iron. The purpose of this investigation was, therefore, to determine the effects of ladle additions of a complex alloy, containing a strengthening element in combination with the "deoxidizing" elements, on the properties of cast iron.

CONSTITUTION OF THE ALLOY

6.   For both technical and economic reasons, a series of copper base alloys, containing different amounts of aluminum, manganese, and silicon was selected as most suitable for investigation.

7.   Aluminum is known to have a powerful effect on the structure of cast iron. It is difficult to use alone, however, as good distribution of the very small amounts required is difficult to control in ordinary foundry practice. Care must be used in adding aluminum, as even a slight excess over that required for "deoxidation" is apparently detrimental to the properties of cast iron as well as a cause of foundry defects in the castings. It has been found that when aluminum is diluted with copper and silicon, these hazards disappear so that the benefits of aluminum can be realized safely and conveniently.

8.   Late additions of silicon also have a beneficial effect on the structure of cast iron. It has been shown that additions of ferrosilicon to the ladle must be carefully adjusted, as the use of excessive amounts introduces foundry difficulties and lowers the mechanical properties of the iron. Silicon, as well as aluminum, appears to function to better advantage when it is diluted with a relatively large amount of a strengthening alloy.

9.   Copper was selected as the base material for these alloys because it was felt that its effects on the properties of medium carbon cast irons were particularly desirable and because of its low cost. It has been shown[9] that copper accelerates the rate at which free carbide breaks down to form pearlite and graphite more than it affects the breakdown of pearlite to ferrite and graphite. This tends to maintain a uniform, pearlitic cast iron in spite of the minor changes in the carbon and silicon contents which frequently occur during a day's operation. In addition, copper reduces the chill in thin sections and reduces porosity in thick sections. The more uniform and denser iron has improved machinability along with increased strength and hardness. Copper also increases the fluidity of molten cast iron and improves its casting qualities.

10.   Based on these considerations, alloys containing from

1 to 10 per cent aluminum, 0 to 25 per cent manganese, 5 to 25 per cent silicon and 50 to 94 per cent copper with small amounts of iron and other impurities were made up in the laboratory. After preliminary tests an alloy containing 6 per cent aluminum, 12 per cent silicon and 80 per cent copper was selected as best adapted to the conditions of the experimental program, namely, the production of relatively low carbon cast irons.

11. This alloy, which will be identified as Copper Alloy No. 3 in this report, is sufficiently friable to be readily crushed to any convenient size. This not only lowers the cost of preparation, but makes it more convenient to proportion exactly so that the proper amounts can be added to the ladle. The use of crushed material also insures rapid solution of the alloy in molten cast iron.

12. The melting point of Copper Alloy No. 3 is less than
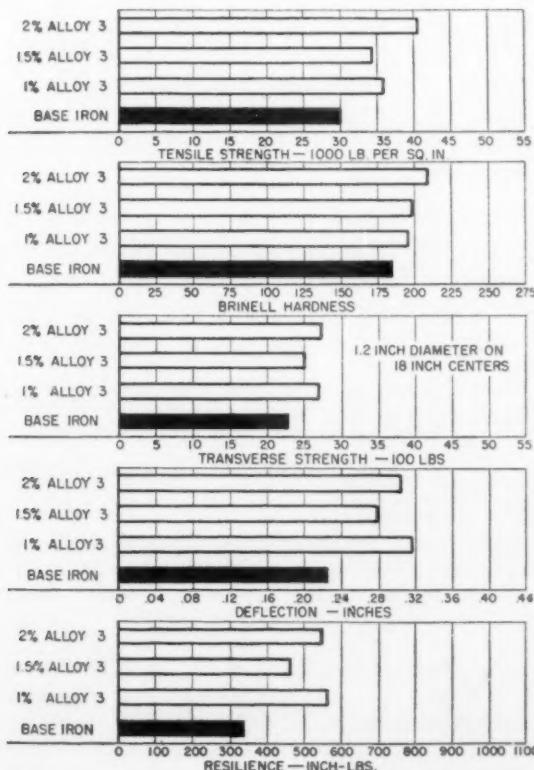
Fig. 2—Average Test Data to Compare the Effects of Varying Percentages of Alloys on the Properties of Gray Cast Iron, Heats 4532, 4533, 4534.

1500°F. Apparently, the alloy does not cause excessive cooling of the molten metal even when added to the ladle in amounts up to two per cent. The low melting point minimizes the danger of segregation. No difficulty was found in obtaining complete solution of the alloy in small ladles at normal cupola temperatures.

13.   The use of recommended amounts of Copper Alloy No. 3 in the ladle does not interfere with the normal effects of special alloy additions of copper, nickel, molybdenum, chromium or vanadium. It is intended for use as a ladle addition to control the structure of the base iron for the most economic production of either plain or alloyed gray iron castings.

EXPERIMENTAL WORK

14.   A number of small heats of cast iron were made and tested to determine the most effective combination of copper, silicon, manganese and aluminum for use as an alloy for ladle additions. The alloy finally selected for investigation contained approximately 80 per cent copper, 12 per cent silicon, and 6 per cent aluminum. A quantity of this material was made up and crushed to pass a 6-mesh screen for ease of handling, proportioning and addition to the molten cast iron.

15.   The effects of additions of various amounts of this alloy on the properties of gray cast iron were then compared to the effects of additions of ferrosilicon, and plain copper. The cast irons used for these tests were melted in a 120 lb. high frequency

Table 1

AVERAGE TEST DATA* TO COMPARE THE EFFECTS OF VARYING
PERCENTAGES OF ALLOYS ON THE PROPERTIES OF GRAY CAST IRON

Physical Properties and Chemical Analyses, 1.2 in. transverse bars, 18-in. span, 0.800-in. tensile specimens	Base Iron Average of three heats	Base Iron Alloy No. 3 Plus 1.0 per cent	Base Iron Plus 1.5 per cent Alloy No. 3	Base Iron Plus 2.0 per cent Alloy No. 3
Tensile Strength, lb. per sq. in.	29,000	36,000	34,500	40,500
Brinell Hardness	179	197	199	210
Transverse Strength, lb.	2,190	2,680	2,520	2,740
Deflection, in.	0.240	0.317	0.281	0.304
Resilience, in. lb.	350	570	465	550
Total Carbon, per cent	3.23	3.25	3.24	3.17
Silicon, per cent	1.86	1.93	2.05	1.98
Manganese, per cent	0.79	0.78	0.80	0.78
Sulphur, per cent	0.05	0.04	0.06	0.05
Phosphorus, per cent	0.09	0.10	0.09	0.09

* Heats 4532, 4533, 4534.

induction furnace and cast into green sand molds. Melting and pouring temperatures were controlled by means of an optical pyrometer, and recorded. Standard practice was used for all tests. All ladle additions were made in accordance with recommended practice for small ladles. Sufficient metal was tapped into the ladle to completely cover the bottom. The addition material was then added at the base of the metal stream while the ladle was being filled. The values for mechanical properties reported in the following tables are the averages of four or more tests.

EXPERIMENTAL RESULTS

The Effect of Different Amounts of Copper Alloy No. 3 on The Properties of Gray Cast Iron

16. The purpose of the first series of tests was to determine
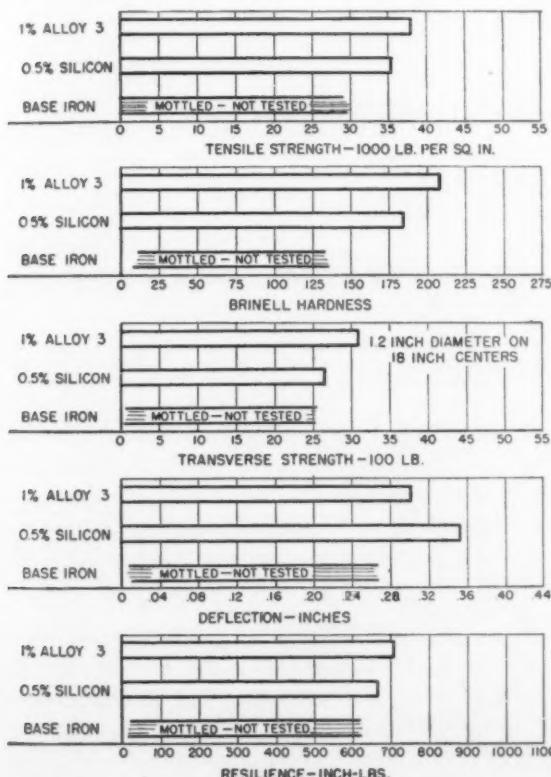
Fig. 8—AVERAGE TEST DATA TO COMPARE THE EFFECT OF 1 PER CENT OF ALLOY No. 3 ON THE PROPERTIES OF GRAY CAST IRON WITH THAT OF 0.5 PER CENT Si AS FERROSILICON, HEATS 4565, 4582, 4567. BASE IRON: TOTAL CARBON 3.27, SILICON 1.22.
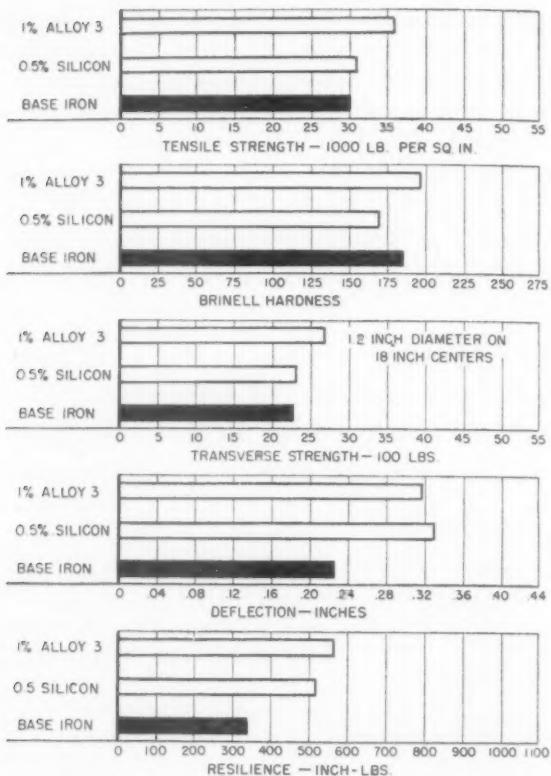
FIG. 4—AVERAGE TEST DATA TO COMPARE THE EFFECT OF 1 PER CENT OF ALLOY NO. 3 ON THE PROPERTIES OF GRAY CAST IRON WITH THAT OF 0.5 PER CENT SI AS FERROSILICON. HEATS 4565, 4532, 4567. BASE IRON: TOTAL CARBON 3.26, SILICON 1.81.

the optimum amount of Copper Alloy No. 3 to be used as a ladle addition to cast iron. The data are shown in Table 1 and Fig. 2. It is evident that additions of 1, 1.5 and 2.0 per cent of Copper Alloy No. 3 improve all of the properties tested but that additions of more than 1 per cent are neither particularly advantageous nor harmful.

17. These results indicate that unlike ferrosilicon, the use of excessive amounts of Copper Alloy No. 3 does not promote the formation of shrinks, blow holes or other foundry defects. Examination of the structure indicated that the irons treated with Copper Alloy No. 3 were completely normal while the untreated irons contained a considerable quantity of the undesirable modified graphite.

18. The values for resilience indicate an increase of about 65 per cent while the Brinell hardness increased about 13 per cent.

*The Effect of Additions of 1 per cent Copper Alloy No. 3
Compared with Additions of 0.5 per cent Silicon as Ferrosilicon
On the Properties of Different Gray Cast Irons.*

19. The first series of tests indicated that satisfactory results are obtained by the addition of 1 per cent Copper Alloy No. 3. A second series of tests was made to show the effects of additions of 1 per cent Copper Alloy No. 3 to irons of different carbon and silicon contents and to compare the effects of Copper Alloy No. 3 with the effects of additions of 0.5 per cent silicon as ferrosilicon containing 78.64 per cent Si and 2.01 per cent Al. The compositions of these irons were balanced to produce medium high test irons without ladle additions.
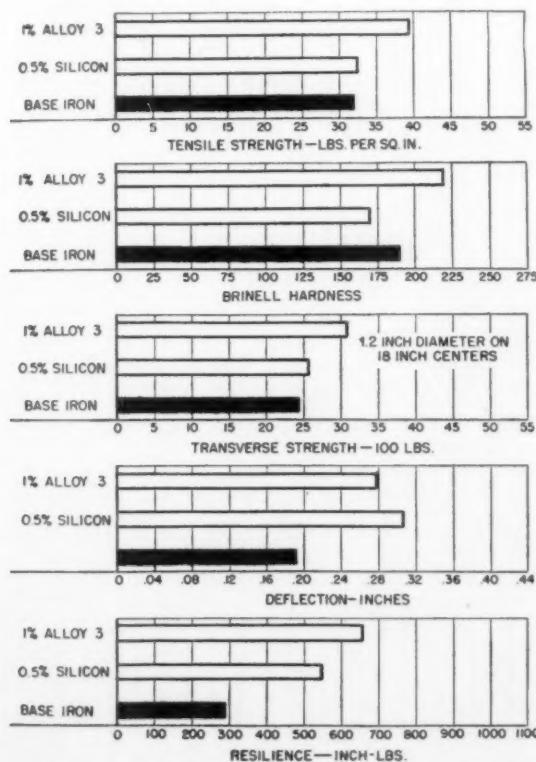
FIG. 5—AVERAGE TEST DATA TO COMPARE THE EFFECT OF 1 PER CENT OF ALLOY No. 3 ON THE PROPERTIES OF GRAY CAST IRON WITH THAT OF 0.5 PER CENT SI AS FERROSILICON, HEATS 4565, 4582, 4567. BASE IRON: TOTAL CARBON 3.03, SILICON 2.21.

Table 2

AVERAGE TEST DATA† TO COMPARE THE EFFECT OF 1 PER CENT OF ALLOY NO. 3 ON THE PROPERTIES OF GRAY CAST IRON WITH THAT OF 0.5 PER CENT SILICON AS FERROSILICON

Physical Properties and Chemical Analyses 1.2 in. transverse bars, 18 in. span, 0.800 in. tensile specimen	T.C. 3.27 per cent Si 1.22 per cent Base Iron — not tested. Mottled.	Base Iron plus 0.5 per cent Si	Base Iron plus 1 per cent Alloy 3	Base Iron T.C. 3.26 per cent Si 1.81 per cent	Base Iron plus 0.5 per cent Si	Base Iron plus 1 per cent Alloy 3	Base Iron T.C. 3.03 per cent Si 2.21 per cent	Base Iron plus 0.5 per cent Si	Base Iron plus 1.0 per cent Alloy 3
Tensile Strength, lb. per sq. in.		35,500	38,000	29,000	30,500	36,000	32,000	32,500	39,500
Brinell Hardness		185	209	179	170	197	189	170	219
Transverse Strength, lbs.		2,660	3,080	2,100	2,420	2,680	2,440	2,570	3,090
Deflection, In.		0.356	0.302	0.240	0.334	0.317	0.192	0.308	0.278
Resilience, In. lb.		670	710	350	540	570	290	550	660
Total Carbon, per cent	3.27	3.27	3.27	3.26	3.21	3.25	3.03	2.97	2.98
Silicon, per cent	1.22	1.56	1.32	1.81	2.32	1.93	2.21	2.60	2.33
Manganese, per cent	0.70	0.70*	0.70*	0.78	0.78*	0.78*	0.81	0.81*	0.81*
Sulphur, per cent	0.06	0.06*	0.06*	0.04	0.04*	0.04*	0.06	0.06*	0.06*
Phosphorus, per cent	0.08	0.08*	0.08*	0.10	0.10*	0.10*	0.08	0.08*	0.08*

* Values assumed from base iron analysis
† Heats 4565, 4582, 4567

20. The results of these tests are shown in Table 2 and Figs. 3, 4 and 5. As indicated in Fig. 3, the base iron containing 3.27 per cent carbon and 1.22 per cent silicon was mottled as cast and therefore was not tested. Both ferrosilicon and Copper Alloy No. 3 graphitized this iron sufficiently to eliminate mottle in the test bars poured from iron treated in the ladle.

21. A comparison of the irons treated with ferrosilicon and Copper Alloy No. 3 indicates that the irons treated with Copper Alloy No. 3 were equal in resilience to the irons treated with ferrosilicon and superior in strength and hardness. The tendency toward modified structures is apparently completely overcome by either ferrosilicon or Copper Alloy No. 3.

22. These results were obtained by making the desired ladle additions to the same base iron, so that the final composition of the
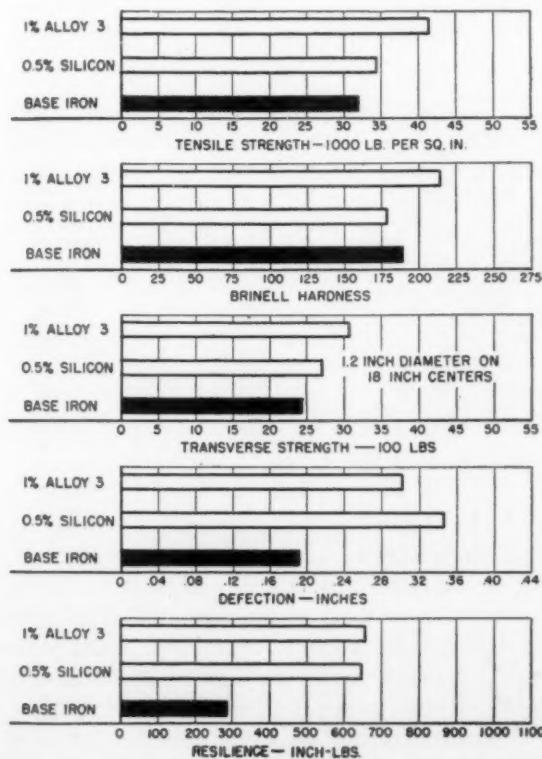
Fig. 6—Average Test Data to Compare the Effects of Ferrosilicon and Alloy No. 3 on the Physical Properties of Cast Irons with Similar Final Analysis, Heats 4565, 4566, 4570.

Table 3

AVERAGE TEST DATA* TO COMPARE THE EFFECTS FERROSILICON
AND ALLOY NO. 3 ON THE PHYSICAL PROPERTIES OF
CAST IRONS WITH SIMILAR FINAL ANALYSIS

Physical Properties and Chemical Analysis 1.2 in. transverse bars, 18 in. span, 0.800 in. tensile specimens	Base Iron No ladle Addition	Base Iron Treated with 0.5 per cent silicon in the ladle	Base Iron plus 1 per cent Alloy No. 3
Tensile Strength, lb. per sq. in. ...	32,000	34,500	41,500
Brinell Hardness	189	179	215
Transverse Strength, lb.	2,440	2,700	3,080
Deflection, in.	0.192	0.348	0.302
Resilience, in. lb.	290	650	660
Total Carbon, per cent	3.03	3.08	2.97
Silicon, per cent	2.21	2.35	2.25
Manganese, per cent	0.81	0.74	0.80
Sulphur, per cent...............	0.06	0.06	0.06
Phosphorus, per cent	0.08	0.08	0.08

* Heats 4565, 4566, 4570.

Table 4

AVERAGE TEST DATA† TO COMPARE THE EFFECTS OF VARYING PER-
CENTAGES OF COPPER SHOT ON THE PROPERTIES OF GRAY
CAST IRON WITH THAT OF 1 PER CENT ALLOY NO. 3

Physical Properties and Chemical Analyses 1.2 in. transverse bars, 18 in. span, 0.800 in. tensile specimens	Base Iron Average of Three Heats	Base Iron plus 1.5 per cent Copper	Base Iron plus 2.0 per cent Copper	Base Iron plus 3.0 per cent Copper	Base Iron plus 1.0 per cent Alloy No. 3
Tensile Strength, lb. per sq. in.	30,500	33,500	36,000	36,500	38,500
Brinell Hardness	189	212	212	222	206
Transverse Strength, lb.	2,470	2,690	2,610	2,550	2,800
Deflection, in.	0.233	0.241	0.211	0.202	0.285
Resilience, in. lb.	365	390	320	290	515
Total Carbon, per cent	3.24	3.21	3.12	3.13	3.17
Silicon, per cent	1.84	1.80	1.82	1.80	1.93
Manganese, per cent	0.84	0.84*	0.84*	0.84*	0.84*
Sulphur, per cent	0.06	0.06*	0.06*	0.06*	0.06*
Phosphorus, per cent	0.10	0.10*	0.10*	0.10*	0.10*

* Values assumed from base iron analysis
† Heats 4562, 4563, 4564

iron depended to a degree on the ladle addition used. In Table 3
and Fig. 6, the data have been rearranged to permit a comparison
of the effects of Copper Alloy No. 3 with that of ferrosilicon on
irons of about the same final composition. This comparison con-
firms the conclusion that the irons treated with Copper Alloy No.
3 are superior in strength and toughness to the irons treated with
ferrosilicon. While the values for resilience are about the same,
the values for deflection are somewhat less for the irons treated
with Copper Alloy No. 3. The values for resilience indicate an
increase of 128 per cent for the irons treated with Copper Alloy

No. 3 over the base iron, with an increase in Brinell hardness of only about 6 per cent.

The Effect of Additions of 1 Per Cent Copper Alloy No. 3 Compared with Additions of Copper Shot

23.   A series of tests was made to compare the effects of additions of 1 per cent Copper Alloy No. 3 with the effects of ladle additions of copper shot in amounts of 1.5, 2.0 and 3.0 per cent. As in previous tests all ladle additions were made to the same base iron. These data are shown in Table 4 and Fig. 7. It is evident that for this particular analysis, the addition of more than 1.5 per cent copper tends to lower the values for deflection and resilience.
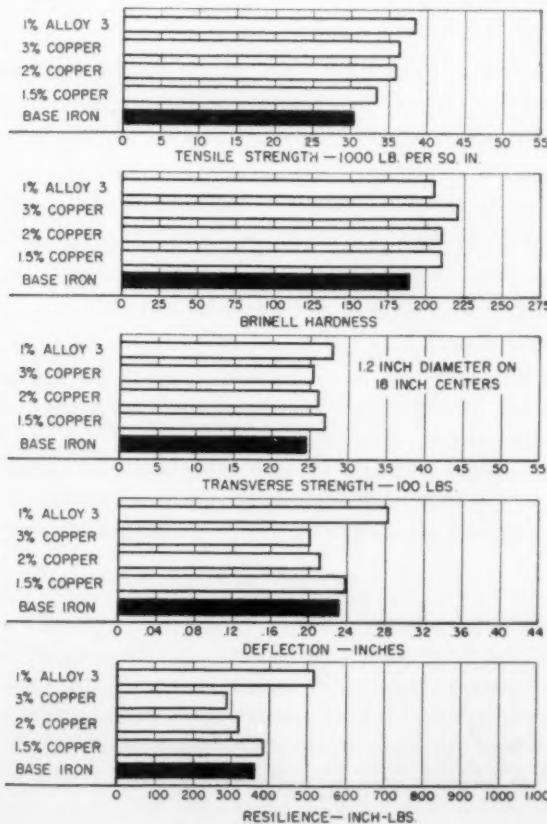
Fig. 7—Average Test Data to Compare the Effects of Varying Percentages of Copper Shot on the Properties of Gray Cast Iron with That of 1 Per Cent Alloy No. 3, Heats 4562, 4563, 4564.

24. The copper additions that were made are equivalent in graphitizing power to from 0.5 to 1.5 per cent silicon. In order to realize the full value of such large additions of copper, the silicon content should be lowered by an equivalent amount. It is evident that 1 per cent of Copper Alloy No. 3 is much more effective as a strengthening agent than copper alone. This is due to its effect on the structure of the iron. The combination of controlled structure and the strengthening effect of the alloying agent results in the best combination of properties.

CONCLUSIONS

(1) An alloy of copper, silicon and aluminum in the correct proportions has a beneficial effect on both the physical and engineering properties of cast irons.

(2) The iron is improved by the addition of such an alloy by the elimination of modified structures and by the refinement of graphite, generally attributed to copper alone.

(3) The copper, aluminum, silicon alloys should be useful in the foundry to offset the effect of unforeseen changes in composition and graphite distribution during regular production.

(4) The copper, aluminum, silicon alloys provide a convenient means for the addition of copper to cast iron.

(5) For the irons tested, the addition of one per cent of Copper Alloy No. 3 results in an improvement in all the properties measured. Values for tensile strength range from 20 to 60 per cent higher, transverse strength, 15 to 40 per cent, deflection 30 to 70 per cent and resilience 60 to 140 per cent with an increase of Brinell hardness of only 5 to 15 per cent in the treated as compared to the untreated irons.

FUTURE WORK

25. At the time of writing this report, the Copper Alloy No. 3 has only been tested under carefully controlled experimental foundry conditions. The next step in the program will be to test the alloy under ordinary commercial conditions. It is believed that alloys containing less aluminum and silicon will be equally effective as Copper Alloy No. 3 when used with medium and high carbon cupola irons. This will be determined by a series of tests on commercial irons which will be reported at a later date.

ACKNOWLEDGMENT

Bibliography

1—Sisco, F. T., *"The Alloys of Iron and Carbon,"* McGraw Hill Co., New York, 1937, 777 pp. p. 317.

2—Coyle, F. B. and Houston, D. M., *"High Strength Cast Iron,"* Trans. A. F. A., 1929, Vol. 37, pp. 469-484.

3—MacPherran, R. S., *"High Test Cast Iron,"* Trans. A. F. A., 1929, Vol. 37, pp. 76-82. Fdry. Trade Jnl., 1932, Vol. 45, pp. 16-19, 25.

4—Smalley, O., *"High Test Cast Iron,"* Trans. A. F. A., 1929, Vol. 37, pp. 485-500.

5—Lemoine, R. P., *"Cupola High Test Cast Iron,"* Trans. A. F. A., 1934, Vol. 42, pp. 745-761.

6—Crosby, V. A. and Herzig, A. J., *"Late Additions to Cast Iron,"* The Foundry, 1938, Vol. 66, pp. 28-30, 73.

7—Comstock, G. F. and Starkweather, E. R., *"Comparative Effects of Late Additions of Titanium and Silicon to Gray Cast Iron,"* Trans. A. F. A., 1938, Vol. 46, pp. 353-373.

8—McElwee, R. G., *"Deoxidation and Graphitization of Cast Iron,"* Trans. A. F. A., 1938, Vol. 46, pp. 341-352.

9—*"Copper in Cast Steel and Iron,"* The Copper Development Association, London, England, 1937, 136 pp.

DISCUSSION

Presiding: A. L. BOEGEHOLD, General Motors Corporation, Detroit.

C. O. BURGESS[1] *(Written discussion):* The authors are to be congratulated on a paper that so clearly brings out the manner in which a ladle addition of either ferrosilicon or copper alloy No. 3 will eliminate eutectic or modified graphite. It is felt, however, that the conclusions regarding the comparative effect of ferrosilicon and their copper-aluminum-silicon alloy (copper alloy No. 3) are open to some question. As pointed out by the authors themselves, the irons of Table No. 2 are not comparable, and conclusions as to the relative effect of ferrosilicon

[1] Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y.

and copper alloy No. 3 can hardly be drawn from irons so widely different in both silicon content and hardness.

Closer correlation is attempted in the single heats of each type listed in Table No. 3 but the sum of the carbon and silicon is still appreciably higher in the ferrosilicon treated iron than in the iron treated with copper alloy No. 3. There is also a wide difference in hardness between the two irons.

In the opinion of the writer, a rigid comparison of two or more ladle addition alloys can be made if the final carbon and silicon composition, and probably more important, the hardness of the treated irons in a transverse section, are similar before determination of their respective strengths. The authors also conclude that an addition of the copper alloy No. 3 yields a tougher iron. This would appear to be in question in view of the higher deflection of the ferrosilicon treated irons. Deflection is certainly one measure of the ability of an iron to resist stress without failure.

These specific criticisms are not intended to detract from the general high quality of this paper. The authors' method of test is of decided interest and serves to emphasize the growing importance of the ladle treatment of cast iron.

F. J. COOK[2] *(Written discussion):* I am very interested in this paper by Messrs. Schnee and Barlow on copper additions to cast iron. In paragraph 10 the authors state that after preliminary tests, they finally selected an alloy containing 6 per cent aluminum, 12 per cent silicon and 80 per cent copper. I believe it would add considerably to the value of an already interesting paper if the authors would amplify the reasons that led them to select this special composition.

V. H. SCHNEE and T. BARLOW *(Authors' written closure):* Replying to Mr. Cook, the preliminary tests referred to were the same as those reported in the paper; namely, tests for tensile strength, transverse strength, deflection, resilience, Brinell hardness, etc. When the work on this alloy was started, we, of course, had only a rough idea of exactly what the best composition would be to obtain the desired results. Consequently, a series of five alloys were made, varying the percentages of copper, silicon and aluminum and one or two other elements. The cast irons were treated with all five of these alloys to determine which one had the greatest beneficial result. The best alloy was found to be that known as No. 3, under the conditions of these tests, consequently, Alloy No. 3 was used for the remainder of the work. However, the authors would like to point out, as did Dr. Schneidewind, that these tests were made on induction furnace cast irons and were consequently more highly modified than would be expected in normal foundry practice. Consequently, further tests have been made utilizing the other compositions of copper, silicon and aluminum to determine the best composition for other melting processes. It has been found in

---

[2] Edgbaston, Birmingham, England.

this regard that an alloy containing only 2 per cent to 3 per cent aluminum is sufficiently powerful for normal cupola operation, and is therefore to be preferred to Alloy No. 3 for use as a ladle addition to cupola cast iron.

Replying to Mr. Burgess, there are two methods of comparing the effects of the ladle additions. The first is by comparing its effects on the cast irons of initially the same composition without taking into account the change in composition due to the ladle additions themselves. This method of comparison is based on the fact that ladle additions frequently have to be used on the cast iron as it comes from the cupola spout at a given composition with no possibilty of making any compensation for any change in composition due to the ladle addition. In other words, if a ladle addition, such as ferrosilicon, does change the composition of the cast iron, this becomes merely one of its drawbacks as it is not always possible to compensate for this increase in silicon. The other method of comparing irons and the effect of ladle additions upon them is as stated by Mr. Burgess, on irons of the same final chemical composition. This is done by varying the initial composition to allow for the change which is to be expected from the addition of the alloy. This suggestion of Mr. Burgess is very good, and has, in fact, already been taken care of in Fig. 6. However, the authors do not think it is possible to make a comparison of the effect of the ladle addition, keeping both the final chemical composition and the Brinell hardness the same, due to the fact that two different ladle additions have different effects on the Brinell hardness; and, therefore, if irons are compared on the same analysis, the different ladle additions must give different Brinell hardness values or if they are based on the same Brinell hardness, the different ladle additions would necessarily have to be added to cast irons of different compositions.

In regard to the effect of Alloy No. 3 on toughness, it is correct that deflection is certainly one measure of the ability of iron to resist stress without failure. However, this is only one measure. A complete measure of toughness can only be had from the resilience which combines both the transverse strength and the deflection and gives excellent agreement with impact tests made on a modified Charpy machine.

The authors feel that Mr. Burgess' remarks were very well taken and we appreciate the opportunity to clear up one or two points under question.

Hydrogen in Solid White Cast Iron

By H. A. Schwartz* and G. M. Guiler*, Cleveland, Ohio

Abstract

A method for the determination of hydrogen in solid white cast iron by direct combustion in oxygen is described. It is shown that the hydrogen content may range from about two to about fifteen ten thousandths of one percent. It is shown that melting under hydrogen or the presence of rust in the charge increases the hydrogen content and that hydrogen escapes rather rapidly from iron at say 800°C. (1475°F.). Atomic hydrogen deposited electrolytically on the surface of white iron is absorbed and raises the hydrogen content to about that absorbed by molten iron from hydrogen gas. This hydrogen is also promptly expelled on heating. No attempt is made to study the effect of hydrogen an any property of the solvent iron.

Introduction

1. Much is written about the effect of hydrogen on ferrous metals, but little quantitative information as to the hydrogen content of the alloys under discussion is disclosed. Without attempting any scholarly documentation we recall to the readers' minds Boyles' probably correct inference as to the effect of hydrogen on the form of graphite in pig iron, Boeghold's earlier work on the effect of moisture content of cupola and blast furnace blast on the properties of gray iron and his Campbell lecture mentioning the effect of hydrogen on graphitization. Some metallurgists see a relation, via hydrogen content, between rusty scrap and foundry losses and there is a voluminous literature correlating "shatter cracks," notably in railway rails, with hydrogen.

2. We do not seek to add to the literature on the effect of hydrogen on white cast iron, but to supply an apparent lack of

---

*Manager of Research and Research Chemist respectively, National Malleable and Steel Casting Co.

knowledge as to the amount of hydrogen which white iron may contain. Vacuum fusion methods for hydrogen have been in use but apparently with some lack of satisfaction. An eminent metallurgist in reporting to the writer certain analyses, kindly made in his laboratory by the vacuum fusion method (on steel) wrote in part: "Although we do not have confidence in the method for determining the exact quantity of hydrogen, we would place its percentage below 0.0001 in each sample."

3. Not greatly encouraged hereby to install the ornate equipment for vacuum fusion, we experimented with a direct combustion method which we have seen frequently alluded to in the literature, for example in Scott's "Standard Methods of Chemical Analysis," fourth edition, but never described in detail so far as we now recall, and finally worked out a useful procedure.

DISCUSSION OF APPARATUS

Combustion Furnace

4. A combustion furnace similiar to the type used for carbon determination. We use a Burrell High Temperature Furnace energized by a tap transformer, but any tube furnace capable of 1050°C. (1922°F.) would be suitable. The combustion tube used is a "High Temperature McDanel," 34 inches long and one inch
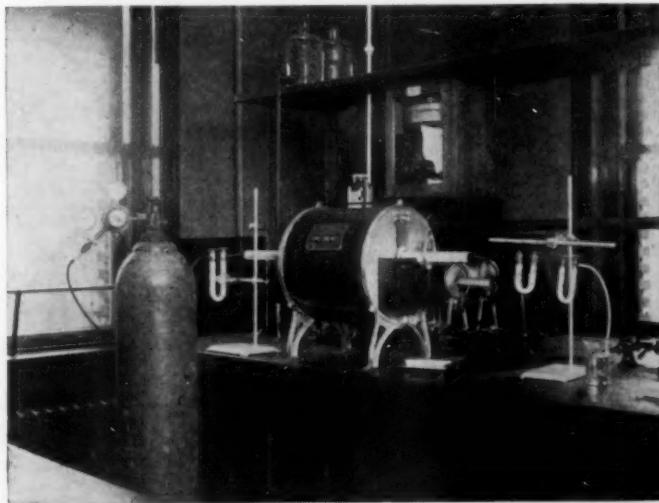
FIG. 1—ARRANGEMENT OF COMBUSTION APPARATUS USED IN THE DETERMINATION OF HYDROGEN.

inside diameter. At both the intake and outlet ends of the tube one-hole rubber stoppers were used. The apparatus has since been improved by eliminating the stoppers using a tube reduced at the outlet and to take a rubber tube directly and by closing the inlet with a ground glass cap on a glass sleeve on the combustion tube. The intake end was 12 inches from the furnace and the outlet end 8 inches from the furnace.

5. As a sulphur trap a glass cylinder about 2 inches long containing a column of coarsely powdered lead chromate about $1\frac{1}{2}$ in. long completely filling the tube and supported by asbestos plugs at each end is placed inside the combustion tube at the outlet end just far enough away from the hot zone so that the temperature of the lead chromate does not exceed 550°C. (1022°F.). This position is determined by the fact that lead chromate decomposes at 600°C. (1112°F.). The diameter of the cylinder is such that it fits neatly into the combustion tube and takes up the entire cross section.

Sample Container

6. A "Zircofrax" boat containing 90 mesh alundum is used as a container for the sample during combustion. The boat used is $4\frac{3}{4}$ in. long over all and about $\frac{3}{4}$ in. wide. The Zircofrax boat is made by the Carborundum Company, Niagara Falls, N. Y.

Oxygen

7. The Oxygen used is the regular tank gas as furnished by the Air Reduction Sales Company.

8. As a drier of the oxygen between the cylinder and the inlet end of the furnace, a glass stoppered U tube containing P_2O_5 is used. The end of the U tube toward the furnace should be well packed with asbestos to prevent the P_2O_5 from blowing out into the combustion train.

9. The purity of the oxygen is indicated by the fact that the gas streaming for hours through the hot furnace does not increase the weight of the weighing tube.

10. The water formed from the combustion of the hydrogen is collected and weighed in a glass stoppered U tube containing P_2O_5. The weight of the absorption bulb and P_2O_5 is about 55 grams.

11. To prevent the possible sucking back of air during the time the iron is burning and consequent contamination of the weighing

tube by water from the air in the absorption bulb, another U tube containing P_2O_5 is connected to the outlet side of the weighed absorption tube.

12.   As a bubble indicator, a glass tube dipping into a beaker containing sulphuric acid is connected to the outlet side of the trap tube by a piece of rubber tubing.

Furnace Temperature

13.   The temperature of the combustion furnace is maintained between 985 and 1040°C. (1800 and 1900°F.).

14.   The gas is bubbled at a rate of about a liter in twenty minutes. The powdered sample is dried at 100°C. (212°F.) before using.

Balance

15.   The push rod for the combustion boat and the alundum which is used to cover the sample during combustion are kept in a muffle furnace at 1000°C. (1832°F.) between determinations. A high grade balance is required, having a sensitivity of about 0.025 Mg, i.e. capable of weighing to one-fourth of the usual 0.1 Mg divisions on the scale beam. When weighing, the U tube is hung to the beam by a loop of fine copper wire rather than laying it on the pan. Allow the U tube to hang in the balance about three minutes before weighing. To disconnect the weighing tube after a determination, pull off the tube going to the trap tube first, then close the stop-cock next to the furnace and pull off the tube going to the furnace. Lastly, close the other stop-cock and after wiping the tube off with a clean, dry towel, hang it in the balance ready for weighing.

Determination Time

16.   The time used for bubbling the gas for each determination is $1\frac{1}{4}$ hours. If at any time this appears not to be sufficient, it is recommended that the time be increased rather than speed up the bubbling. The train must be dry and give no blank for at least the period of time of a determination. The temperature of the boat when the sample is put into it is about 100°C. (212°F.).

PROCEDURE IN DETERMINING HYDROGEN

17.   When the apparatus described above is assembled and dry, the procedure is as follows: Weigh a 2 gram sample and burn and weigh. This is the blank. Then burn a 5 gram sample and

weigh. The difference between 5 grams and 2 grams is the water from the hydrogen contained in 3 grams. This weight is then calculated to percent hydrogen on a 3 gram sample.

$$18.016 : 2.016 :: \text{wt.} : x$$

$$\frac{\text{Value of } x}{3} = \% \text{ Hydrogen.}$$

18.   The opening and closing of the furnace and introduction of even a warm boat and sample involves a fairly large blank of say 1 Mg. The size of this "blank" has been observed to be independent of the size of the sample and hence presumably unrelated thereto. The same hydrogen content is obtained if 2 gram, 5 gram and 10 gram samples are burned irrespective of which pair of sample sizes is chosen for calculation.

RELIABILITY OF THE METHOD

19.   The National Bureau of Standards very kindly put at our disposal three steel bars each of which had had its hydrogen content determined in each of four laboratories. The details of the methods used are to be found so far as reported in "Cooperative Study of Methods for the Determination of Oxygen in Steel," National Bureau of Standards Research Paper 976 (1937). The results in comparison with those by our method were as given in Table 1.

Table 1

Mark	2	4	7
From	0.00009	0.00007	0.0001
National	0.0001	0.0001	0.0003
Bureau of			
Standards	0.00016	0.0002	0.0004
Report	0.0008	0.0003	0.00054
Average	0.00029 +	0.00017 —	0.00034 —
Author's results	0.00018	0.00011	0.00020

It may be noted that the present method gives results somewhat below the average of the others but in all cases within the range of values obtained by others. The degree of agreement obtained by the various laboratories is not especially encouraging but the direct combustion method seems no less credible than the others.

Miscellaneous Data

20. We may quote some of the hydrogen contents obtained on some white cast irons as given in Table 2.

Table 2

Furnace	Hydrogen in 0.0001 Per Cent	Furnace	Hydrogen in 0.0001 Per Cent
Fuel fired rotary	14.0	Cupola-air	5.0
Fuel fired rotary	1.9	Cupola-air	6.0
Rocking electric	5.0	Cupola-air	9.0
Rocking electric	1.8	Cupola-air	8.0
Cupola-air	7.0	Cupola-air	2.0
Cupola-air	6.0	Cupola-air	4.0
Cupola-air	5.0	Cupola-air	5.0
Cupola-air	4.0	Cupola-air	7.0
Cupola-air	4.0	Cupola-air	5.0
Cupola-air	5.0	Cupola-air	7.0
Cupola-air	6.0	Cupola-air	6.0
Cupola-air	6.0	Cupola-air	8.0

Note: The cupola-air furnace data are from duplexing operations.

21. The hydrogen content is to some extent related to the presence of rust on the scrap. A three day average run using rusty scrap in cupola air furnace duplexing yielded 0.00062 per cent H_2 as against 0.00052 per cent H_2 for clean sprue. The ladle addition of metallic alloys, Mn, Cr, Mo and V have invariably been accompanied by quite large reductions of H_2 content.

22. A piece of hard iron containing 0.0005 per cent H_2 was melted, held molten for several hours and allowed to freeze all in an atmosphere of H_2 at atmospheric pressure. The hydrogen was redetermined and found to be 0.0015 per cent, a value so far found only once on a commercial iron. After heating 8½ hours at 800°C. (1470°F.) the H_2 content fell to 0.0007 per cent.

23. Another iron containing 0.0003 per cent H_2 fell to 0.0002 per cent on short heating to 900°C. (1650°F.) and no further after prolonged heating sufficient to attain graphitizing equilibrium. The same iron used as a cathode for the electrolytic decomposition of water for fourteen days contained 0.0015 per cent H_2 which was reduced to 0.0003 per cent by holding 8½ hours in air at 800°C. (1470°F.).

CONCLUSIONS

24. This does not purport to be an erudite discussion of the subject suggested in the title. Still less have we attempted to report on the effects hydrogen retained after freezing, may have on physical properties or graphitizing rates.

25. We hope to have contributed to a field in which conjecture has reigned almost unchallenged an analytical method capable of execution in any laboratory possessing the equipment usual for iron analyses for the determination of hydrogen in solid white cast iron.

26. We believe this method to yield results similar to those obtained by vacuum fusion. Lacking better concordance between the H_2 data from different laboratories, it may be impossible to say what is the exact H_2 content of any sample. We regard our data as at least as credible as those from vacuum fusion.

27. We have shown that white cast iron may contain up to 0.0015 per cent H_2 but frequently much less and that H_2 escapes to a considerable degree and at a considerable rate at 800°C. (1470°F.) and over.

28. We have further shown that the analytical method described gives H_2 values which are concordant with expectations. Iron produced under circumstances which should give higher H_2 is found to contain more of that element than iron which from its history would be expected to contain relatively little of that element.

29. We point to the fact that if hydrogen has important effects, then these effects must be produced by very small changes in H_2 content.

DISCUSSION

Presiding: C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

ALFRED BOYLES[1]: *(Written discussion:)* The analytical method described by the authors is attractive in its simplicity and offers promise as a substitute for vacuum fusion determinations of hydrogen. By way of comparison some results obtained on gray iron by vacuum fusion are given below. These were made at the University of Michigan.

[1] Battelle Memorial Institute, Columbus, O.

Pieces ¾ in. in diameter by 6 in. long were machined from the center of 1.2 in. test bars. These were broken in half and duplicate determinations made (Table 3) of the gases evolved at a temperature of 2500°F.

Table 3

AMOUNT OF GASES IN WEIGHT PER CENT

Sample No.	Per Cent				
	H_2O	H_2	O	O (Calc. as CO)	N_2
57	0.000212	0.000212	0.00415	0.00725	0.00376
	0.000198	0.000362	0.00390	0.00685	0.00372
61	0.000440	0.000240	0.00285	0.00343	0.00402
	0.000400	0.000236	0.00238	0.00416	0.00398
47	0.000360	0.000192	0.00202	0.00354	0.00396
	0.000310	0.000176	0.00148	0.00259	0.00415
147	0.000336	0.000090	0.00354	0.00620	0.00390
	0.000720	0.000164	0.00398	0.00695	0.00425
151	0.001020	0.000210	......	......	0.00322
	0.000750	0.000170	......	......	0.00309
155	0.000670	0.000382	0.00185	0.00324	0.00543
	0.000190	0.000182	0.00128	0.00224	0.00613

In addition the composition of the gas evolved was determined. Table 4 gives the per cent by volume of the various gases withdrawn at 2500°F. The ordinary chemical analyses of the bars are given in Table 5.

Table 4

PER CENT BY VOLUME OF VARIOUS GASES WITHDRAWN AT 2500°F.

Sample No.	Per Cent			
	H_2O	H_2	CO	N_2
57	2	27	47	25
61	6	28	32	34
47	5	25	30	40
147	6	13	50	31
151	19	32	..	49
155	5	30	21	44

Table 5

CHEMICAL ANALYSES OF BARS

Sample No.	Per Cent				
	T.C.	Si	Mn	S	P
57	3.04	2.15	0.69	0.064	0.091
61	3.08	2.16	0.72	0.062	0.094
47	2.87	2.17	0.76	0.064	0.093
147	3.06	2.13	0.70	0.063	0.097
151	2.96	2.12	0.68	0.064	0.098
155	2.80	2.22	0.73	0.060	0.096

The figures for hydrogen are of the same order of magnitude as those obtained by the authors. The difference between duplicate tests,

however, indicates a rather large probable error in a single determination and make it difficult to decide whether the figures are actually reliable to four places of decimals.

I should like to ask the authors to list some of their duplicate determinations on white iron. If the combustion method gives more concordant results than vacuum fusion, it may prove to be a useful tool even though the exact hydrogen content is not obtained by either method.

J. L. CAWTHON, JR.[2]: Does Dr. Schwartz know anything about the hydrogen content of cupola-electric furnace iron. It is noticed that in his table he shows hydrogen contents for various types of iron, but he does not have cupola direct-arc electric furnace iron. Has the author any ideas as to whether or not such an iron might have more hydrogen in it or less than metal melted with fuel. The reason I ask that is because of a theory I heard expressed one time as a result of quite extensive practical experiments—not laboratory experiments—to eliminate porosity in cast steel and, in desperation, during an epidemic of such porosity, the incidence of the porosity was checked up against atmospheric humidity. And although the curves were not qualitatively analogous, there was some quantitative analogy between the curves. And although, in the effort to eliminate this porosity, all the fancy deoxidizers and all the garden variety ones such as vanadium, had been used without success, finally someone had an idea that there was a hydrogen fixation from the electric arc, and the only way they could see how to get that out was to prolong the oxidizing period in the heat cycle, and that had very definite results. This is just a question I would like to know if you have an opinion on, sir.

J. B. CAINE[3]: I would like to know the procedure the author is using here, in regard to crushing or drilling. What about the hydrogen loss in the operation? Is it possible to use a solid piece? The reason I ask that is because the Germans have definitely established a very great pressure in the center of large sections, and if you start drilling into the large sections, the hydrogen may escape; the accuracy is gone before you start. Also what would prevent water condensation before you get to your P_2O_5 tube? I notice in the picture there is quite a long connection. Is there any danger of condensation there?

DR. SCHNEIDEWIND[4]: The author is to be congratulated for bringing about a method for the determination of hydrogen, because I know at the University, where they are running vacuum fusion, they will report the hydrogen to a client if he demands it, but they do not guarantee its accuracy. The vacuum fusion method is not as accurate for hydrogen, as it is for oxygen and nitrogen.

I would be interested to know if Dr. Schwartz has run any annealing tests on irons having the maximum difference in hydrogen content. There is a chance there that we might have differences in annealing rate.

    [2] Development Engineer, Malleable Founders' Society, Cleveland, O.
    [3] Metallurgist, The Sawbrook Steel Casting Co., Cincinnati, Ohio
    [4] University of Michigan, Ann Arbor, Mich.

I think Dr. Schwartz did not emphasize enough an important point which is that the gas analysis is only what is left in a sound piece of metal after it has solidified and is not necessarily a measure of the gas content of the liquid iron as it is solidifying, and the gas content during solidification certainly influences the way it solidifies. But you can not analyze for it. Some of it goes out in the atmosphere from the molten metal; some goes out in blowholes, and some may be dissolved, and you can not analyze for it later. The residual hydrogen may perhaps give an indication of the total hydrogen present in the molten state.

CHAIRMAN JOSEPH: Hydrogen might be the cause of a lot of cracks and shrinks that occur during the time that the moisture is high in the blast, as you mentioned in the early part of your paper.

MEMBER: Dr. Schwartz have you ever attempted to determine whether there is any difference in the skin of an as-cast white iron sample and the core, anything to explain this apparent discrepancy in the paper.

DR. SCHWARTZ (*written closure*): Mr. Boyles' data on gas content of cast iron by vacuum fusion methods are most welcome both for purposes of record and as a comparison with the authors' data. It happens that the original weighings underlying the data of the paper are now rather inconvenient of access. We take from current records of duplicate determinations of hydrogen on six samples of white cast iron the following data as typical. The weights tabulated (Table 6) represent the difference, in mg, of the increment of weight of the P_2O_5 tubes when burning a 2 gram and a 10 gram sample of iron, one combustion immediately following the other.

Table 6

WEIGHT OF H_2O (MG) FROM 8 GRAMS OF SAMPLE

	I Mg.	II Mg.	Average Mg.	Per Cent Departure from Average
A	0.35	0.37	0.36	$\pm$ 3
B	0.48	0.52	0.50	$\pm$ 4
C	0.54	0.61	0.56	$\pm$ 4
D	0.39	0.47	0.43	$\pm$ 10
E	0.30	0.32	0.31	$\pm$ 3
F	0.56	0.64	0.60	$\pm$ 6

It would seem therefore that under the conditions of our experiment we may expect the individual pairs of observations to fall between 3 per cent and 10 per cent away from the average of the two. We have not attempted a statistical analysis of the data we have from the viewpoint of standard deviations. We note that at least in these six determinations the highest value is always in column II which is also the column in which the individual weights are the highest. It would seem

therefore that some further gain of reproducibility will result, as might be expected, by procedures which would further minimize the blank. We would certainly adopt any refinements in this direction which came to our attention believing this to be the most vulnerable point in the method.

Replying to Mr. Cawthon it may be said that since the date of the meeting Mr. Joseph has kindly furnished us with a sample of cupola-electric hard iron upon which an oxygen content of 0.00083 per cent was obtained.

Replying to Mr. Caine's inquiry, we have usually burned our samples reasonably promptly after pulverizing; that is to say we do not pulverize the material until we are ready to start the analysis. We do pulverize all we expect to use for the analysis of a given hard iron at once and then store it in a manner which will keep it dry. We have so far found no notable differences between samples burned in rather small pieces and samples crushed to pass say a 40 mesh sieve. It is expedient to use rather coarse powder, for finely powdered material may oxidize so rapidly as to create a partial vacuum in the apparatus and spoil the result. Though recognizing the possibility of mechanical loss of hydrogen in crushing, this over rapid reaction with oxygen is the only difficulty we have had with finely powdered material. We have experienced no difficulty from water condensing in the outlet tube. The outlet is only as warm as conductivity and the warm gas within keep it, but since we pass O_2 gas to constant weight, the dry gas sweeps any moisture which might condense onward into the P_2O_5 tube. When making analyses continuously it is often possible to sweep out the train completely by adhering to a definite time.

Answering Dr. Schneidewind: — We as yet know nothing of the effect of hydrogen on annealing or indeed about whether it stays in until annealing temperatures are reached. Nor do we know whether hydrogen escapes while freezing. Experiments along both lines are under consideration.

We are quite in accord with those who point out that hydrogen may have effects while metal freezes and then escape, but we know of no observations as to the real facts.

We have thought it impracticable to determine whether there was more hydrogen or less at the surface or at the center of a casting until we know at least a little about the average hydrogen content. The sample containing a very high hydrogen concentration was included as a matter of interest. We know no reason why it should have been so very high, but have no more reason to doubt that analysis than any other.

It may be a matter of interest to say that the addition of almost any metallic alloy to liquid fuel-melted metal reduces the hydrogen content materially. Further discussion of this observation may be reserved for the future.

Influence of Pouring Ladles on Quality of Red Brass

R. W. PARSONS,* MANSFIELD, OHIO

Abstract

The present subject seems to have been largely neglected in the literature. Gassed metal, metal which exudes, and metal which penetrates cores and molds is discussed. The gassed condition is acquired through contact with "green" pouring ladles and is independent of the melting furnace. Some lining materials aggravate the condition but none were found to be without effect. It is possible to preheat ladles sufficiently to permit their use in "green" state but this condition was not regularly attained in practice. Taking a "heat up," after the preheat, was found to eliminate trouble from "green" ladles and no bad effects resulted when the "heat up" metal was poured back into the furnace. New crucibles, preheated to some extent, caused a violent boiling of the metal but, surprisingly enough, metal quality was actually improved by this contact with new crucibles. The findings may be applied to the melting furnace, to explain the gassing of metal which has been melted in a freshly patched furnace.

INTRODUCTION

1. The metal condition to be discussed is characterized by a discolored fracture which, a decade or two ago, almost any foundryman would have called "oxidized." The appearance is something like that caused by silicon contamination except that the bad surface is absent.

2. One of the pioneers in the reversal of this emphasis on the evils of oxidation, presented a paper[1] at the 1922 meeting of the American Institute of Metals, which is just as applicable now as it was in those days. In this paper another writer is quoted[2] as having listed the common causes of gassed metal in order of their importance as follows: superheated metal, dirty furnaces, low quality metals or those previously subjected to bad melting practice,

---

*Metallurgist, Ohio Brass Co.

[1]Woyski, Bruno and Boeck, J. W., *"Gas Absorption and Oxidation of Non-Ferrous Metals,"* Trans. A.I.M.E. (1923). vol. 68, p. 861.

[2]Clarke, R. R., *"Avoiding Evils of the Cauliflower Pouring Head,"* The Foundry (1919), vol. 47, p. 121.
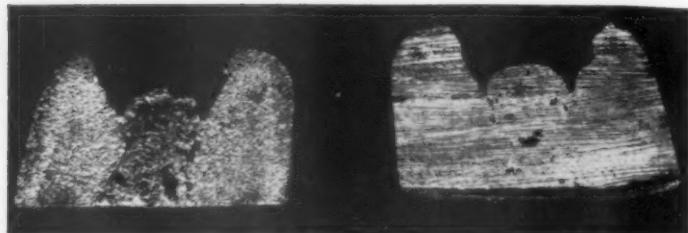
FIG. 1—SHOWING TOP OF A RISER WHICH EXUDED. (ACTUAL SIZE.) IN THE ETCHED SPECIMEN (LEFT) THE POROUS EXUDED METAL WAS RAPIDLY ATTACKED BY THE NITRIC ACID. (ETCHANT: NITRIC ACID WITH 15 PER CENT OF HYDROCHLORIC ACID.)

poor grade of fuel, use of newly lined or damp ladles, indiscriminate mixing of scrap or illogical combinations of metal. Exception was taken[1] to several of the above points and the fact was brought out that the furnace atmosphere is the most important cause of gassed metal. The paper goes on to discuss the influence of the reducing atmosphere of the indirect arc furnace. In the discussion, W. M. Corse suggested the possibility of work with the induction furnace being useful in this connection.

3. The above material is quoted because of the reference to exudation and the statement regarding "use of newly lined or damp ladles," and the fact that the present work has to do principally with metal from the induction furnace. We feel that there has been far too little emphasis on the part played by pouring ladles and hope this presentation may do something toward remedying this condition.

EXUDATION

4. We use the term exudation to cover: (a) "Tin or lead sweat"; (b) "Purging" or "coming up" of sprues and risers (see Fig. 1); (c) Certain types of "burning in" (into either molds or cores).

5. Another American Institute of Metals paper[3] reported on exudations on bars for rolling, several analyses (supported by G. H. Clamer and others) being given which showed tin and lead enrichment in the exuded metal. These authors advanced a theory of "inverse segregation," so called because they found an inversion of the average composition of outside layers as compared to centers. A photograph was included which showed a channel at a grain boundary which they had traced from the exuded metal, $\frac{1}{4}$ in. toward the center of the bar.

[3] Price, W. B. and Phillips, A. J., *"Exudation on Brass and Bronze,"* Transactions, Inst. of Metals, A.I.M.E., 1927, p. 81.

Exudation Due to Gas

6. The consensus seems to be that exudation is a result of dissolved gas, reducing in character, which forces the low melting point constituent between the grains of the solidified outer shell. In casting of billets the effect may be due solely to hydrostatic pressure within the solidified outer skin.

Table 1

ANALYSIS OF A BUTTON FROM A SHRINK CAVITY OF A RISER

	Exuded Metal	Riser	Nominal
Copper	76.49	84.90	85
Tin	7.72	3.79	4
Lead	8.29	3.06	3
Zinc	7.50	8.25	8

7. It has been noted[4] that an inflammable gas is given off during exudation. One of the better examples of this, we observed during solidification of a "pop" riser in a mold poured at high temperature, where the metal rolled over a rather large area which was giving off a great deal of gas and steam.

Analyses of Exuded Metal

8. A button which exuded into the shrink cavity of a riser was analyzed, as was the bottom portion of the riser, and results are shown in Table 1 along with the nominal composition of the alloy. Metal which penetrated sharp sand cores was analyzed on two different occasions. The sample from the cored hole was 57.63 per cent sand and the metallic portion was found to be as shown in Table 2.

Table 2

ANALYSIS OF METAL WHICH PENETRATED SHARP SAND CORES

	First	Second	Nominal
Copper	71.11	75.35	85
Tin	9.33	8.81	4
Lead	8.73	6.10	3
Zinc	10.83	9.74	8

9. The similarity between the analyses indicate that the conditions are related, in fact the "burning in" was associated with exudation in the risers—sometimes the risers did not shrink at all.

10. Similar analytical results were obtained (Table 3) on another alloy. "Whiskers" from the inside of a casting and fins from the riser on a heavy casting are shown with the nominal composition.

[4] Boeck, J. W., Discussion p. 492 of Bolton, J. W. and Weigand, S. A. Paper entitled "*Incipient Shrinkage in Some Non-Ferrous Alloys*," Trans. Inst. of Metals Division, A.I.M.E., 1929, pp. 475-497.

11.   It is interesting to note the difference between the exuded metal from the two alloys above. In the first cases, the tin and lead bear approximately the same relationship to each other as they have in the nominal composition; but in the second instance the lead (and zinc) enrichment seems to be much greater than is the case with the tin content.

METAL PENETRATION WHICH IS NOT EXUDATION

12.   All roughness of cored surfaces cannot be credited to exudation. The analyses of Table 4 were made upon samples collected from rough surfaces, due to the smallness of the samples the analyses may be somewhat out of line but hardly enough so as to warrant a pronouncement of exuded metal.

EFFECT OF TEMPERATURE

13.   Exudation was more pronounced at the higher pouring temperatures (2300°F.) but the condition has been detected in badly gassed metal poured at more moderate temperatures. Metal which exuded was readily traced to the first heats in the morning and much effort was expended investigating these first heats (after the holdover period); the effect of a charcoal covering, during melting, was also studied. The condition persisted in spite of changes in melting practice. While studying any changes in practice, we were interested in getting a prompt answer with the result that we generally made such checks with the first metal from the new ladles. Results were uniformly disappointing.

Table 3
ANALYSIS OF WHISKERS AND FINS FROM CASTING AND RISER

	Whiskers	Fins*	Nominal
Copper	69.30	73.93	81.5
Tin	4.29	3.16	3
Lead	14.12	10.96	7
Zinc	12.29	11.95	8.5

* This metal came from the first heat of the week (but not a green" ladle) from an indirect arc furnace and it is believed that the metal became gassed through contact with the freshly patched furnace. Due to a lack of production, there has been no opportunity to check this point.

14.   Since there was not always a demand for hot metal from the first heats, and since the balance of the metal was poured elsewhere at lower temperatures, the results were inconsistent. Some time elapsed before two ladles, from the same first AM heat, were poured at high temperature and it could be proven that the gassed metal was coming from the first *ladle* rather than the first heat. Once the fact was established, a program was undertaken to investigate the matter.

Findings Based on Appearance of Fractures

15.   Fractures, through the base of sprues, form the bulk of the data collected and opinions regarding metal quality are based upon the appearance of these fractures. Presentation of such data is a difficult matter and we know of no way to do this properly aside from actual distribution of the fractured specimens.

16.   Fig. 2 shows what happens when we attempt to photograph a group of representative fractures—the results are not

Table 4
Analysis of Metal Collected From Rough Surfaces

	First	Nominal	Second	Nominal
Copper	79.61	81.5	84.26	85
Tin	3.08	3	5.14	4
Lead	6.44	7	2.96	3
Zinc	10.87	8.5	7.64	8
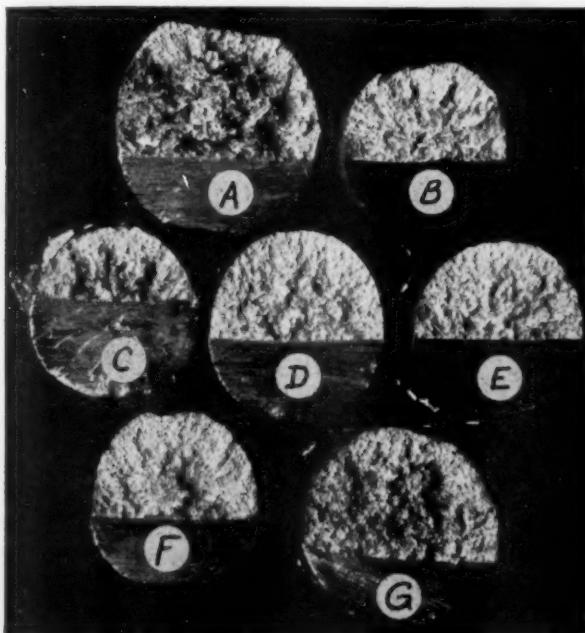
Fig. 2—Fractures Through The Base of Sprues. (actual size—(A) is the same as No. 1, (B) same as No. 3, (C) same as No. 6, (D) same as No. 9, (E) same as No. 8, (F) same as No. 40, and (G) same as No. 54 of Table 5.) (A) Discolored (orange) fracture of metal, gassed by "green" ladle, which "burned" into core and mold.—(B) Metal from same heat as A carried in once-used ladle, metal not perfect but good quality.—(C) Metal, gassed by "green" ladle, which "burned in," fracture discolored about like B.—(D) Metal from same heat as C shows good quality when poured from used ladle.—(E) Same as D except from another ladle.—(F) Excellent metal condition obtained from a first ladle which had been internally and externally heated before use. (G) Bad fracture obtained from "green" ladle washed with an electrically fused alumina cement which contained considerable organic bond—the orange color was not so prominent.
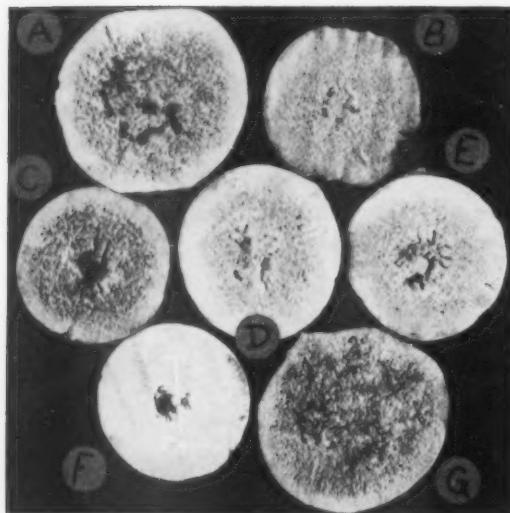
FIG. 3—DEEP ETCHED SECTIONS OF SAME SAMPLES AS FIG. 2. (ACTUAL SIZE). ETCHED IN COMMERCIAL NITRIC ACID PLUS 15 PER CENT HYDROCHLORIC ACID. ARRANGEMENT IDENTICAL TO THAT OF FIG. 2.

particularly informative. When the identical pieces are ground and etched, some idea of soundness may be obtained (the lighter ones are the most dense), even though the contrast of colors is still lacking. Fig. 3 shows a photograph of etched sections having an arrangement identical to that of Fig. 2.

LADLE LININGS

17. The ladles in question are the steel shells, or bowls, rated at 150 lb. capacity, which are carried by the foundry supply houses. The shells are lined with a mixture of refuse molding sand (re-bonded with bentonite) and 20 mesh fire clay, with or without ground firebrick. The mixture is tempered about like molding sand; riddled; rolled into place; and washed with high temperature cement.

18. Should the preheating time be reduced, through failure to get the ladles on the heater at the usual time, it is obvious that the ladles will not be properly dried and heated. There will be a violent boiling action when such ladles are first filled with metal from the furnace[2], and the metal should be poured into pigs.

19.   We cannot stress too strongly that the ladles used in
these experiments were not the product of sloppy drying technique
—the term "green ladle" is used only to indicate one which has
not received metal. After $1\frac{1}{2}$ to $1\frac{3}{4}$ hr. over a gas burner, the
lining is at a bright red heat and any reasonable person viewing
them would agree that they had been properly handled and were
fit to be used without further treatment.

20.   When the condition of exudation was most pronounced,
the metal might "spit" a little after the ladle was filled; usually
jets of blue flame at the metal line were the only indication; often
no unusual action could be detected, even though the metal was
found to have been effected.

EFFECT OF LADLES ON METAL

21.   Of the experiments listed in Table 5, Nos. 1 and 3,
2 and 4, 6 and 9, 30 and 31, 37 and 38, and others, show the effect
on the metal of the first and second use of the ladle lining. With
the exception of No. 40, with the ladle heated both externally and
internally, and the surprising results from new crucibles (Nos. 47
and 48), the metal was always better after the ladle had been used
once. This held true even in cases where the drying had been
unusually good and the metal from the green ladle was excellent—
there would be a slight difference in favor of the second ladle.
Experiments Nos. 14 to 18 check the matter of a first heat poured
into ladles used previously, further demonstrating that the first
heat is without influence.

22.   It was possible (see Nos. 10, 33, 43 and 44) to fire the
ladles so that they could be used satisfactorily, but we never knew
when this had been accomplished and it was found much better
practice to take a "heat up" as shown by 7 and 8, 11 and 13.

23.   Experiments Nos. 37 and 38 are after minor repairs to
the heater and show that the trouble was not eliminated.

24.   A new, and greatly improved, ladle heater was built in
an endeavor to conserve fuel; it was thought that a "heat up"
would not be required after the superior preheating equipment
was available, but experiments Nos. 58 to 61 show that such was
not always the case.

25.   Experiments Nos. 21 and 22, also No. 28 following Nos. 23
to 27, show no harmful results from pouring metal back into the

Table 5

Data Sheet Showing Effect of "Green" Ladle Linings on Red Brass†† as Judged by Fractures

No.	Date	Alloy†	Heat Up	Use of Ladles	Poured By	Pouring Temp.°F.	Sprue	Risers Shrink	Burn In	Fracture*	Remarks
1	9-13-38	4	No	1st*	A	2120	Flat	....	Yes	Gassed	
2		4	No	1st	B	2140	Flat	....	Some	Gassed	
3		4	....	2nd	A	2080	OK	....	No	Good	
4		4	....	2nd	B	2100	OK	....	No	Good	
5		4	....	10th	—	2120	OK	....	No	Good	
6	9-14-38	4	No	1st*	B	2100	OK	....	No	Gassed	
7		4	Yes*	1st	A	2160	OK	....	Some	Gassed	
8		4	....	2nd	A	2120	OK	....	No	OK	Best fracture of 9-14-38
9		4	....	2nd	B	2150	OK	....	No	OK	
10		4	No	1st PM	A	2100	OK	....	No	OK	Slowly dried all AM
11	9-15-38	4	Yes*	1st	B	2160	OK	....	No	OK	
12		4	No	1st	A	2060	OK	....	No	Good	
13		4	....	2nd	A	2150	OK	....	No	Poor	Crucible melted††
14		4	....	2nd	B	2140	OK	....	No	Excellent	
15		5	....	3rd	B	2140	OK	Yes	No	Excellent	First heat from different furnace
16		5	....	3rd	A	2150	OK	Yes	No	Excellent	First heat from different furnace
17		5	....	4th	B	....	OK	....	No	Excellent	First heat from different furnace
		5	....	4th	A	2050	OK	....	No	Excellent	First heat from different furnace (large sprue)
18	9-16-38	4	Yes	1st	A	2120	OK	....	No	Good	"Heat Up" metal from another furnace
19		4	Yes	1st	B	2080	OK	....	No	Excellent	"Heat Up" metal from another furnace
20		4	....	2nd	A	2060	OK	....	No	Good	

(Table 5—Continued)

	Date										Remarks
21		5	....	3rd	A	2140	OK	Yes	No	Excellent	Effect of pouring back metal used for "heat up"
22		5	....	4th	A	2200	OK	....	No	Excellent	Effect of pouring back metal used for "heat up"
23	9-20-38	5	Yes	1st	A	2300	Exude	No	Some	Poor	Some trouble at high temperature even with "heat up"
24		5	Yes	1st	A	2300	OK	No	Some	Poor	Some trouble at high temperature even with "heat up"
25		5	Yes	1st	A	2140	Flat	No	Some	Poor	Some trouble at high temperature even with "heat up"
26		5	Yes	1st	C	2300	OK	....	No	Good	
27		5	....	2nd	A	2140	OK	Yes	No	Good	
28		4	....	4th	A	2160	OK	....	No	Excellent	Effect of pouring back metal used for "heat up"
29		5	....	?	A	2300	OK	Yes	No	OK	
30	9-21-38	5	No	1st	A	2300	OK	Yes	No	Poor	Heated on best burner
31		5	....	2nd	A	2300	OK	Yes	No	OK	Fracture better than No. 30
32	9-22-38	5	No	1st	A	2300	OK	No	No	OK	Core gassed riser
33		4	No	1st PM	B	2100	OK	....	No	Excellent	Dried all AM
34	9-23-38	5	No	1st	A	2300	OK	Yes&No	Yes	Good&Bad	Progressively worse towards last molds
35		5	No	1st	A	2300	OK	Yes	No	Good	Different cement in another ladle
36		5	No	1st	B	2140	OK	Some	No	OK	Like No. 35
37	9-27-38	4	No	1st	A	2120	OK	....	No	Poor	Heater repaired
38		4	....	2nd	A	2140	OK	....	No	Excellent	
39	9-29-38	4	No	1st	A	2120	OK	....	No	Excellent	Externally heated—shows perfect drying job

(Table 5—Continued)

No.	Date	Alloy†	Heat Up	Use of Ladles	Poured By	Pouring Temp.°F.	Sprue	Risers Shrink	Burn In	Fracture†	Remarks
40		4	No	1st	A	2120	OK	....	No	Excellent	Externally heated—shows perfect drying job (another sample from No. 39)
41		4	....	2nd	A	2150	OK	....	No	Excellent	Externally heated—shows perfect drying job
							Oven dried, not preheated, metal boiled — pigs exuded.				
42	10-7-38	5	No	1st*	A	2120	OK	....	No	Good	Extra holes in shell—best burner
43	11-25-38	4	No	1st	A	....	OK	....	No	Good	Extra holes in shell—best burner
44		4	....	2nd	A	2120	OK	....	No	Poor	Like No. 43—on another burner
45	11-30-38	4	No	1st	B	2100	OK	....	No	Excellent	Like No. 43—on another burner
46		4	....	2nd	B	2120	OK	....	No	Excellent	
47	12-8-38	4	No	New* Crucible	A	2150	OK	....	No	Excellent	Three Samples fractured††
48	12-12-38	4	No	New* Crucible	A	2050	OK	....	No	Excellent	Fractures from first and last molds
49		4	....	Used Ladle	B	2100	OK	....	No	Excellent	Fracture not equal to No. 48
50	12-16-38	4	No	Malleable Ladle	D	2120	OK	....	No	Poor	Shows damage from clay lining
51		4	....	Used Ladle	B	2050	OK	....	No	Excellent	Same metal (No. 50) OK in used ladle
52	10-13-38	4	No.	1st	A	2150	OK	....	No	Good	Mullite or Sillimanite type cement
53		4	....	2nd	A	2160	OK	....	No	Excellent	Mullite or Sillimanite type cement
54	10-14-38	4	No	1st	A	2120	Exude	....	Some	Gassed	Electrically fused alumina with different grain and having less clay and organic bond
55		4	....	2nd	A	2120	OK	....	No	Good	Electrically fused alumina with different grain and having less clay and organic bond

(Table 5—Continued)

56	10-17-38	4	No	1st	—	2150	Flat	....	No	Poor	Electrically fused alumina cement with special clay and no organic bond
57		4	....	2nd	—	2160	OK	....	No	OK	Electrically fused alumina cement with special clay and no organic bond
58	1-10-39	4	No	1st	A	2100	OK	....	No	Good	New heater
59		4	....	2nd	A	2160	OK	....	No	Excellent	
60		4	No	1st	B	2100	OK	....	No	Gassed	New Heater failed to eliminate trouble
61		4	....	2nd	B	2120	OK	....	No	Excellent	

† Alloy 4 is 81½ per cent copper, 3 per cent tin, 7 per cent lead, 8½ per cent zinc.

Alloy 5 is 85 per cent copper, 4 per cent tin, 3 per cent lead, 8 per cent zinc.

†† All metal in table melted in induction furnace, except No. 12 which was crucible melted.

* Means there was visible bubbling after the ladle was filled with metal.

†* The opinions on metal quality, as judged by appearance of fractures, was something on which all who saw them could agree. The rating in order of excellence; Excellent, Good, OK, Poor, Gassed or Bad.

Note—Burners. Some of the burners seemed to work better than others—see Nos. 30, 43, 58. But No. 37, after repairs to heater, and No. 60, after new heater, show need for "heat up."

Cements. Some electrically fused alumina cement, with organic bond, nearly always used (exceptions No. 47, 48, 50, 52, 56 and 57); only the ladles washed solely with this material (Nos. 1 to 10, 23, 34, 39, 40 and 41) produced metal which "burned in." Mullite or sillimanite type cement used after experiment No. 10, in considerable quantity.

furnace after being used for a "heat up"; though theoretically the metal would have to solidify before the gas would be released. However, we did not pour back any quantity of badly gassed metal and therefore we have not proven definitely that two ladles of badly damaged metal would not spoil the resultant heat.

26. In experiment No. 12, crucible melted metal, poured into a "green" carrying ladle, was damaged by contact with the ladle. Since the ladles affected alike the metal from crucible and induction furnace, we conclude the type of furnace to be without influence.

27. Experiment No. 42, where the ladle was oven dried but not fired, came out about as expected with violent boiling and exudation in the ingots poured. Extra holes were drilled in the steel shell to assist escape of steam and facilitate drying; this was apparently successful (Nos. 43 and 44) until the experiment was repeated (Nos. 45 and 46) and it was found to be untrue.

DIFFERENT LINING MATERIALS

28. The worst metal condition (Nos. 1, 2, 6, 23, 34 of Table 5) was obtained from "green ladles" which had been washed with an electrically fused alumina cement, composed of fine grains, which carried considerable clay and organic bond. A similar material, made up of fine to coarse grains, which was lower in clay and organic bond, had some effect (Nos. 54 and 55) but not to the same extent as the more highly bonded material. A third electrically fused alumina cement, without the organic bond, had the least effect of any of this type of high temperature cement.

29. It is not likely that the fused alumina grain has any influence, as it is inert and incapable of giving off gas; the organic bond and the chemically combined water probably do the damage. These cements make a very dense coating which may be more difficult to dry than a more porous one—porosity may be helpful in aiding the escape of gas and steam during the preheat.

30. Note that there were cases (23), when pouring at high temperatures, where the metal was damaged by contact with a ladle which had been given a "heat up," showing how difficult it may be to get rid of all the moisture.

31. If the refractory was red hot clear through, the steel shell would be red hot also; since this is not the case (except in

No. 39), it is safe to assume that the refractory is not heated to a very great depth, and the hotter the metal the deeper the penetration.

32. The mullite or sillimanite type of cement seemed best but these were not without effect and the "heat up" was still necessary; these cements were generally coarser and made a more porous coating.

33. A well preheated lining consisting of fire clay and ground firebrick (No. 50) impaired metal quality, proving that the high temperature cements are not the sole cause even though the worst conditions were obtained through their use. These tests indicate that chemically combined water may be responsible for the damage done to the metal; this view is held by others[1], [5].

34. The behaviour of new crucibles is of particular interest (Nos. 47 and 48). After drying in a steam heated oven, the crucibles were fired to perhaps 1600 to 1800°F. When molten metal was poured in, a violent bubbling action took place, which lasted for a matter of minutes and caused some speculation regarding the wisdom of pouring the metal into castings. The metal quality was actually *improved* by the treatment.

CONCLUSIONS

(1) Tests show that quality of red brass, as judged by appearance of fractures, is quite generally impaired during the first use of a new pouring ladle, even though the ladles seem to have been well dried and thoroughly preheated.

(2) The condition is that of gassed metal, showing fissures and the discolored fracture which characterizes silicon contamination, except that the bad casting surface is absent. Such metal may exude on solidification and may "burn in" to cores and molds.

(3) The cause of the gassed metal is attributed to moisture —chemically combined in the lining material. The worst condition was experienced with ladles washed with a high temperature cement containing an organic bond but all lining materials altered the metal to some extent. The ladle is not the only source, metal may be gassed in the furnace or may become gassed in the mold, but, on the other hand, gassed metal exuded even when poured into dry sand molds.

⁵ Bales, C. E. and Blackburn, A. R., Trans. A.F.A., Vol. 46, 1938, p. 165.

(4)   New clay-graphite crucibles caused the metal to boil violently and "flare" as if it were being badly gassed but metal quality was actually benefited by such treatment.

(5)   Giving the ladles a "heat up" with metal (about 3 min.) was effective in preventing any changes in metal quality during subsequent use.

(6)   Contrary to generally accepted theory, when metal used for the "heat up" was poured back into the furnace, there was no measurable impairment of such metal when poured into castings (from a "used" ladle). When the metal boils appreciably, in all probability, it would be better to pour the metal into pigs.

(7)   The findings may serve to explain the gassing of metal which has been melted in a freshly patched furnace.

ACKNOWLEDGEMENT

DISCUSSION

Presiding: H. M. ST. JOHN, Crane Co., Chicago, Ill.

G. M. THRASHER[1]: I have had considerable amount of experience in the foundries where in the past we have had some trouble with the absorption of something from the new lining of the electric furnace but we were never able to attribute anything in particular to the ladle lining. At one time, when using a lining material for a steel ladle, we found that the temperature drop was so great in the lined ladle, that we adopted an insulated type of ladle. We got a straight-sided crucible with a larger bowl, allowing space for celite insulation, and we rarely had any indication of boiling action in our ladle or pouring pots.

I would like to ask Mr. Parsons if any attempt was made to deoxidize the metal after it was discovered in this condition?

MR. PARSONS: After the metal was poured into the ladles, it went to the pyrometer station where phosphor-copper was added which only made it worse. So, the answer is "Yes" and "No," we added the normal amount of phosphor-copper but we did not make any attempt to improve the condition through deoxidation. There was no attempt to add additional zinc.

MEMBER: Would a slightly perforated ladle allow the gas to go out through the refractory instead of coming out through the ladle?

---

[1] R. Lavin & Sons, Inc., Representative, Elmira, N. Y.

MR. PARSONS: All of the steel shells are perforated in the bottom. We experimented with a shell which had additional holes drilled in the bottom and sides until it looked like a collander, but that didn't seem to help. In the experiments, Nos. 43 to 46, Table 5, the ladle shell was just full of holes, though this point was not mentioned in the abstract which was given.

MEMBER: It has been falsely reported from time to time by different authorities that silicon causes black spots to rise in the metal. Mr. Parsons mentioned that a condition he got from the boiling was similar to silicon. I would like to ask if after skimming he noticed any black material coming up as bubbles and floating on the top?

MR. PARSONS: The answer is "No." I don't know what you mean by "black." What comes to the surface seems to be zinc oxide, for when you skim it off and cool it, it is white not "black."

MR. THRASHER: Another phase of that matter is in the heating of ladles, at times using an oil burner when not sufficiently heated, you get considerable carbon deposit in them, especially around the lower end and top. The ladles are heated very often around the top where the flame is deflected back on the burner, and without sufficient heating at the bottom the carbon deposit might have some tendency to cause the boiling.

G. K. EGGLESTON[2]: We use ladles entirely and have for some twelve years. It may have been our good luck rather than our forethought when we built our ladle heaters. Almost without exception, our ladles are hotter than the metal going into them. Apparently the high temperature of our ladles has kept us free from this difficulty.

I think important the fact that this paper has brought to light a subject that has been haunting brass foundries, that is this peculiar structure Mr. Parsons describes and which he has found is caused by ladles. Others have found indications of it caused by freshly pitched furnaces. I think the paper has more or less opened the line of thought where possibly we can go ahead and determine what this elusive element is that is causing this condition and apparently coming from a number of different sources.

Some years ago we found silicon did this and for a while we thought all of this condition was caused by silicon. We have had to change our minds in recent years because we have conclusively proved other things are causing it. What it is I don't know and from what I can learn others are not sure of the cause.

CHAIRMAN ST. JOHN: I think Mr. Eggleston's remarks are very timely. Most of us are familiar with cases where a fracture similar to that obtained when the metal is contaminated vith silicon occurs,

---

[2] Detroit Lubricator Co., Detroit, Mich.

but which in these cases is evidently not due to silicon, since the pres-
ence of silicon cannot be proved by the most improved methods of analy-
sis and furthermore, the metal cannot be cleansed by methods that have
been demonstrated as effective against silicon. I must add my name to
the people who do not know what the cause of the fracture is.

MR. PARSONS *(Closure):* There seems to be considerable confusion
as regards a possible remedy, probably because of confusion as to the
nature of the defect. It is a gassed condition and, when the metal
freezes, a gas is liberated which will burn, this can only mean a reduc-
ing condition. Manifestly, further deoxidation would be worse than
useless to remedy a condition which already has a reducing character.
Some means of oxidizing, such as blowing air through the metal might
be helpful, though the literature indicates the only way to drive out
gas is to allow the metal to solidify.

We have apparently failed to make it clear that, while boiling is
usually associated with a green ladle, we found much damage resulting
when there had been very little boiling, hardly enough to be noticeable
in some cases. In the case of a new crucible, a violent boiling action
was found to have done no harm, in fact, the metal quality was im-
proved slightly.

Announcement to All Foundrymen

Steel   Non-Ferrous
Malleable   Cast Iron

The 1940 Cast Metals Handbook
Is Off The Press

Bringing to every member of the foundry industry revised data and information on all cast metals. This is the only engineering book of its kind. A book that covers such items as recommendations to designers, recommendations to buyers of castings and four sections on the properties, applications and specifications of cast metals. All four phases of the industry steel, malleable, non-ferrous and cast iron are included.

This is a cloth bound book containing more than 500 pages, over 300 illustrations, charts and tables.

One copy gratis to all members on request.
Price to non-members $5.00.

AMERICAN FOUNDRYMEN'S ASSOCIATION
222 West Adams St., Chicago, Ill.